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NASA TECHNICAL STANDARD

NASA-STD-3001, Volume 2, Revision E

National Aeronautics and Space Administration

Office of the Chief Health and Medical Officer
Controlled by: David Francisco

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Superseding NASA-STD-3001, Volume 2, Revision D

NASA SPACEFLIGHT HUMAN-SYSTEM STANDARD

VOLUME 2: HUMAN FACTORS, HABITABILITY, AND ENVIRONMENTAL HEALTH

DOCUMENT HISTORY LOG

Status	Document Revision	Change Number	Approval Date	Description
Baseline			2011-01-10	Initial Release
Revision	A		2015-02-10	Revision of lunar dust requirement, section 6.4.4.2
Revision	B		2019-09-09	Editorial changes throughout document with addition of the following sections/requirements: 3.5/[V2 3006], 5.2.4/[V2 5008], 6.3.1.3/[V2 6105], 6.6.1.14/[V2 6106], 7.3.2.5/[V2 7085], 8.7.4/[V2 8059], 8.7.5/[V2 8060], 11.1.3.2/[V2 11028], 11.2.3.1/[V2 11029], 11.2.3.2/[V2 11030], 11.2.5.1/[V2 11031], 11.3/[V2 11032], 11.4/[V2 11033], 11.5/[V2 11034], 11.6/[V2 11035], 11.7/[V2 11036], 11.8/[V2 11037], 11.9/[V2 11038], 11.10/[V2 11039], and all of Section 13. Deletion of the following sections/requirements: 3.1/[V2 3001], 3.2/[V2 3002], 3.3/[V2 3003], 3.4/[V2 3004], 3.5/[V2 3005], 6.2.1.4/[V2 6005], 6.2.5.2/[V2 6018], 6.3.1.3/[V2 6028], 6.6.1.1/[V2 6071], 6.6.1.2/[V2 6072], 6.6.2.14/[V2 6086], 7.9.3/[V2 7072], 7.10.5/[V2 7078], 8.1.4/[V2 8004], 8.6.1.2/[V2 8044], 8.6.1.5/[V2 8047], 8.6.1.6/[V2 8048], 8.7.4/[V2 8054], 10.2.1.1/[V2 10029], 10.3.2.4/[V2 10041], 10.3.4.1.1/[V2 10051], 10.5.3.8/[V2 10092], 11.1.2.3/[V2 11004], 11.1.3.3/[V2 11008], 11.2.3.1/[V2 11026] and Section 12. The following sections/requirements were materially changed either in the text of this NASA Technical Standard and/or in the rationale: 1.1, 1.2, 1.3, 1.4, 4.2.2/[V2 4006], 4.4/[V2 4008], 4.8.3/[V2 4014], 5.1.1/[V2 5001], 5.1.2/[V2 5002], 5.1.3/[V2 5003], 5.2.1/[V2 5005], 5.2.2/[V2 5006], 5.2.3/[V2 5007], 6.2.1.2/[V2 6003], 6.2.1.3/[V2 6004], 6.2.2.1/[V2 6006], 6.2.2.2/[V2 6007],

Status	Document Revision	Change Number	Approval Date	Description
				6.2.2.3/[V2 6008], 6.2.3.2/[V2 6011], 6.2.4.1/[V2 6012], 6.2.4.3/[V2 6014], 6.2.5.1/[V2 6017], 6.2.6.1/[V2 6020], 6.2.6.2/[V2 6021], 6.2.7.1/[V2 6022], 6.3.1.1/[V2 6026], 6.3.2.7/[V2 6035], 6.4.4.1/[V2 6052], 6.4.5.3/[V2 6056], 6.4.5.4/[V2 6057], 6.4.8/[V2 6063], 6.5.1/[V2 6064] (Figures 4 and 5), 6.5.2.2/[V2 6066], 6.5.2.3/[V2 6067], 10.6.1.9/[V2 10108], 11.1.2.1/[V2 11006], 11.1.2.2/[V2 11007], 11.1.3.3/[V2 11014], 11.1.6/[V2 11023], 11.2.1.1/[V2 11024], 11.2.2.1/[V2 11025], 11.2.4.1/[V2 11027]
Revision	C		2022-04-20	Editorial changes throughout document with the following sections/requirements that were materially changed either in the text of this NASA Technical Standard and/or in the rationale: 1.1, 1.2, 1.3, 2.1.2, 2.2, 2.3, 3.1, 3.2; 3.2.1/[V2 3006], 4.2/[V2 4013], 4.3/[V2 4015], 5, 5.1.1/[V2 5001], 5.1.2/[V2 5002], 5.1.3/[V2 5003], 5.1.4/[V2 5004], 5.2, 5.2.1/[V2 5005], 5.2.2/[V2 5006], 5.2.3/[V2 5007], 5.2.4/[V2 5008] 6.1/[V2 6001], 6.2, 6.2.1.1/[V2 6002], 6.2.1.2/[V2 6003] and Table 1, 6.2.1.3/[V2 6004], 6.2.2.1/[V2 6006], 6.2.2.2/[V2 6007], 6.2.2.4/[V2 6008], 6.2.3/[V2 6011] and Table 2, 6.2.4.1/[V2 6012] and Figure 2, 6.2.4.2/[V2 6013], 6.2.5/[V2 6017], 6.2.6.1/[V2 6020], 6.2.6.2/[V2 6021], 6.2.7.1/[V2 6022], 6.2.7.2/[V2 6023], 6.2.7.3/[V2 6024], 6.2.7.4/[V2 6025], 6.2.8.1/[V2 6107], 6.2.8.2/[V2 6108], 6.3.1.1/[V2 6026], 6.3.1.4/[V2 6046] and Table 3, 6.3.4.1/[V2 6039], 6.3.4.2/[V2 6040], 6.3.5/[V2 6046], 6.4, 6.4.1.1/[V2 6047], 6.4.1.2/[V2 6048], 6.4.1.3/[V2 6049], 6.4.2/[V2 6050], 6.4.3/[V2 6051], 6.4.4.1/[V2 6052], 6.4.4.2/[V2 6053], 6.4.5.5/[V2 6058], 6.4.5.6/[V2 6059], 6.4.2.1/[V2 6060], 6.4.2.2/[V2 6061], 6.4.4/[V2 6063], 6.5, 6.5.1/[V2 6064] and Figures 3, 5-7, 6.5.2.1/[V2 6065] and Figure 9, 6.5.3/[V2 6069], 6.5.4/[V2 6070], 6.6, Table 6,

Status	Document Revision	Change Number	Approval Date	Description
				Table 7, 6.6.1.2/[V2 6074], 6.6.1.3/[V2 6075], 6.6.1.4/[V2 6076], 6.6.1.5/[V2 6077], 6.6.1.7/[V2 6078], 6.6.1.8/[V2 6079], 6.6.1.9/[V2 6080], 6.6.1.10/[V2 6081], 6.6.1.11/[V2 6082], 6.6.1.12/[V2 6083], 6.6.1.14/[V2 6085], 6.6.1.15/[V2 6106], 6.7, 6.7.1.1/[V2 6089], 6.7.1.2/[V2 6090], 6.7.1.4/[V2 6092], 6.7.1.5/[V2 6093], 6.7.2/[V2 6094]/6.8.1.1/[V2 6095], 6.8.1.2/[V2 6097], 6.8.1.3/[V2 6098], 6.8.1.4/[V2 6099], 6.8.1.5/[V2 6100], 6.8.2, 6.8.2.1/[V2 6102], 6.8.2.2/[V2 6103], 6.8.2.3/[V2 6104], 7.1.1.2/[V2 7002], 7.1.1.3/[V2 7003] and Table 13, 7.1.1.4/[V2 7004], 7.1.1.5/[V2 7005] and Table 14, 7.1.1.6/[V2 7007] and Table 15, 7.1.2.6/[V2 7014], 7.2.1/[V2 7016], 7.2.2/[V2 7017], 7.3.1.1/[V2 7020], 7.3.1.2/[V2 7021], 7.3.1.4/[V2 7023], 7.3.1.5/[V2 7024], 7.3.2.2/[V2 7085], 7.3.2.3/[V2 7035], 7.4.1/[V2 7038], 7.4.4/[V2 7041], 7.4.3/[V2 7042], 7.5.1/[V2 7043], 7.5.2/[V2 7045], 7.5.4/[V2 7049], 7.6, 7.6.1, 7.6.1.5/[V2 7054], 7.6.2, 7.6.2.3/[V2 7057], 7.8.1.1/[V2 7064], 7.8.1.2/[V2 7065], 7.8.2/[V2 7069], 7.9.1/[V2 7070], 7.9.2/[V2 7071], 7.10.1/[V2 7074], 7.10.3/[V2 7076], 7.11.1/[V2 7079], 7.11.3/[V2 7081], 7.11.5/[V2 7083], 8.1.1/[V2 8001], 8.1.2/[V2 8005], 8.1.3/[V2 8006], 8.2, 8.2.1/[V2 8007], 8.2.2/[V2 8010], 8.3, 8.3.1/[V2 8013], 8.3.2/[V2 8014], 8.3.3/[V2 8020], 8.3.4/[V2 11005], 8.4.1.1/[V2 8022], 8.4.1.4/[V2 8025], 8.4.2.2/[V2 8028], 8.4.2.3/[V2 8029], 8.4.3.2/[V2 8031], 8.4.3.3/[V2 8032], 8.5, 8.5.1/[V2 8033], 8.5.6/[V2 8038], 8.5.3/[V2 8040], 8.5.4/[V2 8041], 8.5.5/[V2 8042], 8.6, 8.6.1/[V2 8043], 8.6.2/[V2 8045], 8.6.3/[V2 8049], 8.6.4/[V2 8050], 8.7, 8.7.1/[V2 8051], 8.7.6/[V2 8055], 9, 9.1.3/[V2 9003], 9.3.1.11/[V2 9016], 9.3.3.1/[V2 9017], 9.3.3.2/[V2 9018], 9.3.3.3/[V2 9019], 9.3.3.4.1/[V2 9020], 9.3.3.4.2/[V2 9021], 9.3.3.5/[V2 9022], 9.3.3.6/[V2 9023] and Table 21, 9.3.4.2/[V2

Status	Document Revision	Change Number	Approval Date	Description
				9025], 9.3.4.3/[V2 9026], 9.5.2.2/[V2 9031], 9.6.1/[V2 9034], 9.7, 9.7.1.1/[V2 9036], 9.7.1.3/[V2 9038], 9.7.2.4/[V2 9042], 9.7.3.2/[V2 9046]. 9.7.3.3/[V2 9047], 9.7.3.4/[V2 9048], 9.8.1.1.1/[V2 9053], 9.8.2.1/[V2 9059], 9.8.2.5/[V2 9063], 9.8.3/[V2 9064], 10, 10.1.1, 10.1.1.1/[V2 10001], 10.1.1.2/[V2 10002], 10.1.1.3/[V2 10003], 10.1.2/[V2 10004], 10.1.3.2/[V2 10006], 10.1.3.3/[V2 10007], 10.1.5.1/[V2 10015], 10.1.5.2/[V2 10016], 10.1.6.3/[V2 10020], 10.1.6.5/[V2 10022] and Table 22, 10.1.8.1/[V2 10027], 10.2.3, 10.3.4.2.1/[V2 10056], 10.5.3.2/[V2 10086], 10.5.3.3/[V2 10087], 10.5.3.6/[V2 10090], 10.6, 10.6.1/[V2 10100], 10.6.4/[V2 10104], 10.6.5/[V2 10105], 10.6.6/[V2 10106], 10.6.9/[V2 10110], 10.7.2, 11, 11.1.3.6/[V2 11017], 11.1.4.1/[V2 11018], 11.1.4.2/[V2 11019], 11.1.5/[V2 11023], 11.2.1/[V2 11024], 11.2.3.2/[V2 11030], 11.2.6/[V2 11032], 11.3.5/[V2 11039] and Table 26, 12, 12.1, 12.1.1/[V2 12003] 12.1.2.4/[V2 12007], 12.1.3.1/[V2 12010], 12.1.3.2/[V2 12011], 12.1.3.10/[V2 12019], 12.1.3.12/[V2 12021], 12.1.3.15/[V2 12024], 12.1.4.1/[V2 12028], 12.1.4.5/[V2 12032], 12.1.4.8/[V2 12035], 12.1.5.2/[V2 12037], 12.1.6.4/[V2 12041], 12.2/[V2 12044], 12.2.4/[V2 12046] and Table 27, Appendix A-E Deletion of the following sections/requirements: 4.1.1/[V2 4001], 4.1.2/[V2 4002], 4.1.3/[V2 4003], 4.1.4/[V2 4004], 4.2.1/[V2 4005], 4.2.2/[V2 4006], 4.3/[V2 4007], 4.4/[V2 4008], 4.5/[V2 4009], 4.6/[V2 4010], 4.7/[V2 4011], 4.8.1/[V2 4012], 5.2, [V2 5005], 6.2.3.1/[V2 6010], 6.2.4.4/[V2 6014], 6.2.5.2/[V2 6019], 6.3.1.2/[V2 6027] and Table 3, 6.3.1.3/[V2 6105], 6.3.2.1/[V2 6029], 6.3.2.2/[V2 6030], 6.3.2.3/[V2 6031], 6.3.2.4/[V2 6032], 6.3.2.5/[V2 6033],

Status	Document Revision	Change Number	Approval Date	Description
				6.3.2.6/[V2 6034], 6.3.2.7/[V2 6035], 6.3.2.8/[V2 6036], 6.3.2.9/[V2 6037], 6.3.2.10/[V2 6038], 6.3.4.1/[V2 6041], 6.3.4.2/[V2 6042], 6.3.4.3/[V2 6043], 6.3.4.4/[V2 6044], 6.3.4.5/[V2 6045], 6.4.5.1/[V2 6054], 6.4.5.2/[V2 6055], 6.4.5.3/[V2 6056], 6.4.5.4/[V2 6057], 6.5.3.1/[V2 6068], 6.8.1.2/[V2 6096], 7.1.1.5/[V2 7005] and Table 12, 7.1.1.6/[V2 7006] and Table 13, 7.1.2.6/[V2 7013], 7.2.3/[V2 7018], 7.3.1.9/[V2 7028], 7.3.2, 7.3.2.1/[V2 7030], 7.3.2.2/[V2 7031], 7.3.2.3/[V2 7032], 7.3.2.4/[V2 7033], 7.3.2.6/[V2 7034], 7.3.2.8/[V2 7036], 7.3.2.9/[V2 7037], 7.4.2/[V2 7039], 7.5.1/Table 17, 7.5.2/[V2 7044], 7.5.4/[V2 7047], 7.5.5/[V2 7048], 7.8.2/[V2 7067], 7.8.3/[V2 7068], 7.10.4/[V2 7077], 8.1.2/[V2 8002], 8.1.3/[V2 8003], 8.2.2.2/[V2 8008], 8.2.2.3/[V2 8009], 8.2.3/[V2 8012], 8.3.3/[V2 8015], 8.3.4/[V2 8016], 8.3.5/[V2 8017], 8.3.6/[V2 8018], 8.3.7/[V2 8019], 8.3.9/[V2 8021], 8.3.10/[V2 11002], 8.4.1.5/[V2 8026], 8.5.2/[V2 8034], 8.5.3/[V2 8035], 8.5.4/[V2 8036], 8.5.5/[V2 8037], 8.5.7/[V2 8039], 8.5.11/[V2 11003], 8.5.12/[V2 11012], 8.6.1.3/[V2 8046], 9.3.1.10/[V2 9014], 9.3.1.11/[V2 9015], 9.7.2.2/[V2 9040], 9.7.2.3/[V2 9041], 9.7.3.5/[V2 9049], 10.1.6.3/[V2 10019], 10.3.4.2.4/[V2 10059], 10.6.1.4/[V2 10103], 10.6.1.8/[V2 10107], 10.6.1.12/[V2 10111] The following sections/requirements were added throughout this NASA Technical Standard: 3.1.1, 3.2.2/[V2 3102], 3.2.3/[V2 3101], 4.1.1/[V2 4102], 4.1.2/[V2 4103], 4.1.3. 4.1.3.1/[V2 4103], 4.1.3.2/[V2 4104], 6.2.2.3/[V2 6150], 6.2.4.2/Figure 3, 6.2.4.3/[V2 6151], 6.2.4.4/[V2 6152], 6.2.7.3/Table 3, 6.2.7.5/[V2 6153], 6.2.8.1/[V2 6107], 6.2.8.2/[V2 6108], 6.3.2/[V2 6109],

Status	Document Revision	Change Number	Approval Date	Description
				6.3.3/[V2 6110], Table 4, 6.5.5/[V2 6111], 6.5.6/[V2 6112], 6.5.7/[V2 6113], 6.6.1.6/[V2 6115], 6.7.1.2/Figure 12, 6.8.2.4/[V2 6117], 7.1.1.5/[V2 7100], and Table 14, 7.3.1.10/[V2 7101], 7.3.2.1/[V2 7102] and Table 16, 8.4.4/[V2 8101], 8.5.6/[V2 8102], 8.7.6/Table 17, 9.3.1.1/[V2 9101], 9.3.2/Tables 20-25, Figures 14-18, 9.3.2.1/[V2 9102] and Table 26, 9.3.2.2/[V2 9103] and Table 27, 10.1.1.2/Table 29, 10.1.1.5/[V2 10200], 10.1.6.6/[V2 10201] and Table 31, 11.1.6/[V2 11100], 11.5/[V2 11101], Appendix F
Revision	D		2023-09-13	Editorial changes throughout document with the following sections/requirements that were materially changed either in the text of this NASA Technical Standard and/or in the rationale: Section 1, 2.2, 3.4/[V2 3101], Section 5, 6.1/[V2 6001], 6.2.1.1/[V2 6002], 6.2.1.2/Table 6.2-1, 6.2.2.1/[V2 6006], 6.2.2.4/[V2 6008], 6.2.3.3/[V2 6014], 6.2.4.3/[V2 6151], 6.2.6.3/Table 6.2-3, 6.2.7.1/[V2 6107], 6.3.1.3/[V2 6046], 6.3.3/[V2 6110] and Table 6.3-1, 6.4.1.2/[V2 6048], 6.4.2.2/[V2 6061], 6.4.3/[V2 6062], 6.5/Intro, 6.5.1/[V2 6064] and Table 6.5-2 and Figures 6.5-(2-7), 6.5.2.3/[V2 6067], 6.5.3/Table 6.5-9, Section 6.6, 6.7.1.2/[V2 6090] and Table 6.7-1, 6.7.1.3/[V2 6091], 6.7.1.4/[V2 6092], 6.7.1.5/[V2 6093], Section 6.8.1, 6.8.2.4/[V2 6117], 7.1.1.2/[V2 7002], 7.1.1.3/[V2 7003] and Table 7.1-1, 7.1.1.5/[V2 7100] and Table 7.1-2, 7.1.2.3/[V2 7007] and Table 7.1-3, 7.1.2.4/[V2 7010], 7.1.3.4/[V2 7012], 7.3.2.1/Table 7.3-1, 7.5.3/[V2 7046], 7.6.1/Intro, 7.8.2/[V2 7069], 7.11.4/[V2 7082], 7.11.5//[V2 7083], 8.3.2/[V2 8014], 8.5.1/[V2 8033], 8.5.5/[V2 8042], 8.7 Intro, 8.7.1/[V2 8051], 8.7.5/[V2 8053], 8.7.6/[V2 8059], 8.7.7/[V2 8060], 8.7.8/Table 8.7-2, 8.7.9/[V2 8056], 8.7.10/[V2 8057], 8.7.11/[V2 8058], Section 9.3.2, 9.3.3.6/[V2 9023], 9.7.1.5/[V2 9036], 9.7.2.1/[V2 9038], 9.7.3.1/[V2 9039],

Status	Document Revision	Change Number	Approval Date	Description
				9.7.3.4/[V2 9044], 9.7.4.2/[V2 9045], 9.7.5.2/[V2 9035], 9.7.6.1/[V2 9051], 9.8.1.1.3/[V2 9055], 9.8.1.2.3/[V2 9058], 9.8.2.1/[V2 9059], 9.8.2.3/[V2 9061], Section 10, 11.1.1/[V2 11001], 11.2.1/[V2 11024], 11.2.4/[V2 11027], 12.1.2.1/12004, 12.1.4.6/[V2 12033], 12.2/Tables 12.2-1 and 12.2-2, Appendices A-E Deletion of the following sections/requirements: 5.1.1/[V2 5001], 5.1.2/[V2 5002], 5.1.3/[V2 5003], 5.1.4/[V2 5004], 6.8.1.2/[V2 6097], 6.8.1.4/[V2 6099], 6.8.1.5/[V2 6100], 6.8.1.6/[V2 6101], 7.5.4/[V2 7049], 8.5.6/[V2 8102], 8.7.2/[V2 8052], 10.1.3.3/[V2 10007], 10.1.3.4/[V2 10008], 10.1.3.5/[V2 10009], 10.1.3.6/[V2 10010], 10.1.3.7/[V2 10011], 10.1.3.8/[V2 10012], 10.1.4.1[V2 10013], 10.1.4.2/[V2 10014], 10.1.5.1/[V2 10015], 10.1.5.2/[V2 10016], 10.1.6.1/[V2 10017], 10.1.6.2/[V2 10018], 10.1.6.4/[V2 10021], 10.1.7.1/[V2 10023], 10.1.7.2/[V2 10024], 10.1.7.3/[V2 10025], 10.1.7.4/[V2 10026], 10.2.1.1/[V2 10030], 10.2.1.2/[V2 10031], 10.2.3.1/[V2 10033], 10.2.3.3/[V2 10035], 10.3.1.1/[V2 10036], 10.3.2.1/[V2 10038], 10.3.2.2/[V2 10039], 10.3.2.3/[V2 10040], 10.3.2.4/[V2 10042], 10.3.2.5/[V2 10043], 10.32.6/[V2 10044], 10.3.3.1/[V2 10047], 10.3.3.3/[V2 10049] and Table 33, 10.3.3.4/[V2 10050], 10.3.4.1.2/[V2 10053], 10.3.4.1.3/[V2 10054], 10.3.4.1.4/[V2 10055], 10.3.5.2/[V2 10061], 10.3.5.3/[V2 10062], 10.3.5.5/[V2 10064], 10.3.5.6/[V2 10065], 10.4.1/[V2 10067], 10.4.3.2/[V2 10071], 10.4.3.3/[V2 10072], 10.4.4.1/[V2 10074], 10.4.4.2/[V2 10075], 10.4.5/[V2 10080], 10.4.6.1/[V2 10081], 10.4.6.2/[V2 10082], 10.5.3.2/[V2 10086], 10.5.3.3/[V2 10087], 10.5.3.4/[V2 10088], 10.5.3.5/[V2 10089], 10.5.3.6/[V2 10090], 10.6.1/[V2 10100], 10.6.2/[V2 10101], 10.6.3/[V2 10102],

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Status	Document Revision	Change Number	Approval Date	Description
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Revision	E		2025-05-01	Editorial changes throughout document with the following sections/requirements that were materially changed either in the text of this NASA Technical Standard and/or in the rationale: Section 1.2 Applicability, 6.8.2.4/[V2 6117] The following sections/requirements were added throughout this NASA Technical Standard: 11.3.6/[V2 11040]

FOREWORD

This NASA Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item. This NASA Technical Standard provides uniform technical requirements for the design, selection, and application of hardware, software, processes, procedures, practices, and methods for human-rated systems.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. It may also apply to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center [FFRDC]), other contractors, recipients of grants and cooperative agreements, and parties to other agreements only to the extent specified or referenced in applicable contracts, grants, or agreements.

This NASA Technical Standard establishes Agency-wide requirements that minimize health and performance risks for flight crew in human spaceflight programs. This NASA Technical Standard applies to space vehicles, habitats, suits (extravehicular activity (EVA) and intravehicular activity (IVA)/launch, entry and abort (LEA)), facilities, payloads, and related equipment with which the crew interfaces during spaceflight and lunar and planetary, e.g., Mars, habitation.

Requests for information should be submitted via “Feedback” at https://standards.nasa.gov. Requests for changes to this NASA Technical Standard should be submitted via Marshall Space Flight Center (MSFC) Form 4657, Change Request for a NASA Engineering Standard.

15 Sept 2023

J.D. Polk, DO, EdD, MMM, CPE, FACOEP, FAsMA, FEWM
NASA Chief Health and Medical Officer
NASA Headquarters

Approval Date

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF APPENDICES

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

NASA SPACEFLIGHT HUMAN-SYSTEM STANDARD

VOLUME 2: HUMAN FACTORS, HABITABILITY, AND ENVIRONMENTAL HEALTH

1. SCOPE

The scope of this NASA Technical Standard is restricted to human spaceflight missions and includes activities affecting crew in all phases of the life cycle (design, development, test, operations, maintenance), both inside and outside the spacecraft, while on Earth, in space and on extraterrestrial surfaces.

1.1 Purpose

The purpose of this NASA Technical Standard is to provide uniform technical requirements for crew health, performance, training, medical operations, design, selection, and application of hardware, software, processes, procedures, practices, and methods for human-rated systems. This technical standard has been established to guide and focus the development of the crew health technical requirements as a means of protecting spacefaring crews. NASA-STD-3001, Spaceflight Human-System Standard, is a two-volume set of NASA Agency-level technical requirements established by the Office of the Chief Health and Medical Officer (OCHMO), directed at minimizing health and performance risks for flight crews in human spaceflight programs.
NASA's policy for establishing technical requirements to protect the health and safety of crew and for providing health and medical programs for crewmembers during all phases of spaceflight is authorized by NPD 1000.3, The NASA Organization, and NPD 8900.5, NASA Health and Medical Policy for Human Space Exploration. NPD 8900.1, Medical Operations Responsibilities in Support of Human Space Flight Programs, and NPD 8900.3, Astronaut Medical and Dental Observation Study and Care Program, authorize the specific provision of health and medical programs for crewmembers. NASA's policy is to establish technical requirements for providing a healthy and safe environment for crewmembers and to provide health and medical programs for crewmembers during all phases of spaceflight. Technical requirements are established to maintain crew health and performance, contributing to overall mission success and preventing negative long-term health consequences related to spaceflight. In this NASA Technical Standard, the OCHMO establishes NASA's spaceflight crew health technical requirements for the pre-mission, in-mission, and post-mission phases of human spaceflight.

All technical requirements are based on the best available scientific and clinical evidence, as well as operational experience from Gemini, Apollo, Skylab, Shuttle, Shuttle/Mir (Russian space station), International Space Station (ISS) missions, and Commercial Crew Program (CCP). Technical requirements are periodically and regularly reviewed, especially as the concept of operations and mission parameters for a program become defined and may be updated as new evidence emerges.

NASA-STD-3001, Volume 1: Crew Health, sets technical requirements for fitness for duty, spaceflight permissible exposure limits (PEL), permissible outcome limits (POL), health and medical care, medical diagnosis, intervention, treatment and care, and countermeasures. This volume considers human physiologic parameters as a system, much as one views the engineering and design of a mechanical device. Doing so allows the human-system to be viewed as an integral part of the overall vehicle design process, as well as the mission reference design, treating the human-system as one system along with the many other systems that work in concert to allow the nominal operation of a vehicle and successful completion of a mission.

The technical requirements presented in this volume of the NASA Technical Standard are intended to complement the overall set of human technical requirements for spaceflight, which also includes NASA-STD-3001, Volume 2: Human Factors, Habitability and Environmental Health; OCHMO-STD-100.1A, NASA Astronaut Medical Standards Selection and Annual Recertification; and current medical standards of clinical practice.

NASA-STD-3001, Volume 2: Human Factors, Habitability, and Environmental Health sets technical standards for human system integration, human physical and cognitive capabilities and limitations, and spacecraft (including orbiters, surface vehicles, habitats, and suits) internal environments, habitability, architecture and hardware, and equipment. It also includes technical requirements for ground processing, facilities, payloads, and related equipment, hardware, and software systems with which the crew interfaces during space operations. This volume considers human-system integration where the context is about how the human crew interacts with other systems, including the habitat and the environment. The focus is on performance issues during a mission—whether the human and the system can function together (within the environment and habitat) and accomplish the tasks necessary for mission success.

Combined, these volumes provide Agency technical requirements for an appropriate environment for human habitation, certification of human participants, the necessary level of medical care, and risk-mitigation strategies against the deleterious effects of spaceflight. These technical requirements help ensure mission completion, limit morbidity, and reduce the risk of mortality during spaceflight missions.

NASA/SP-2010-3407, Human Integration Design Handbook (HIDH) is a compendium of human spaceflight history and knowledge and serves as resource for implementing NASA-STD-3001 by providing the background, data, and guidance necessary to derive and implement program- and project-specific requirements that in are in compliance with NASA-STD-3001. It is organized in the same sequence as NASA-STD-3001, Volume 2, and provides useful background information and research findings. The HIDH is also meant to help program planners, designers, and human factors and health practitioners achieve successful integration of humans and systems. A complementary reference document to the HIDH is NASA/TP-2014-218556, Human Integration Design Processes (HIDP). The HIDP describes the "how-to" processes, including methodologies and best practices that NASA has used during the development of crewed space systems and operations. Additional supplementary resource information can be found on the OCHMO Human

Spaceflight and Aviation Standards webpage (https://www.nasa.gov/ochmo/health-operations-and-oversight/hsa-standards/).

1.2 Applicability

This NASA Technical Standard is applicable to human space systems. The technical requirements specified in this volume:

a. Apply to all space exploration programs and activities involving crewmembers.

b. Apply to internationally provided space systems as documented in distinct separate agreements such as joint or multilateral agreements.

c. Are to be made applicable to contractors only through contract clauses, specifications, or statements of work in conformance with the NASA Federal Acquisition Regulation (FAR) supplement and not as direct instructions to contractors.

NPR 8705.2, Human-Rating Requirements for Space Systems, defines the human-rating requirements for space systems. HEOMD-003, Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions is a tailoring of NPR 8705.2 for crewed deep space systems. The intent of this NASA Technical Standard is to be the foundation for the program/project requirements and verification documentation.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program/project, and other Agency documents. It may also apply to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center [FFRDC]), other contractors, recipients of grants and cooperative agreements, and parties to other agreements only to the extent specified or referenced in applicable contracts, grants, or agreements.

The NASA Technical Authorities—Health and Medical Technical Authority (HMTA), Chief Engineer (ETA), and Chief, Safety and Mission Assurance (SMA TA)—assess NASA programs and projects for compliance with NASA-STD-3001. If the program or project does not meet the provisions of this NASA Technical Standard, then the associated risk to the health, safety, and performance of the crew is evaluated by the Technical Authorities.

Technical requirement statements are designated by the acronym of the volume (e.g., "[V2]" for Volume 2), numbered, and indicated by the word "**shall.**" Explanatory or guidance text is indicated in italics beginning in Section 3, Systems Engineering Processes and Requirements. To facilitate requirements selection and verification by NASA programs and projects, a Requirements Compliance Matrix is provided in Appendix D—Table D.2-1.

1.2.1 Program/Project Implementation

Applicability of individual technical requirements may change based on individual program/project parameters and must be considered to ensure cost-effective implementation of this NASA Technical Standard. Therefore, all technical requirements in this NASA Technical Standard are applicable to all NASA human spaceflight programs/missions/projects unless determined otherwise and agreed to by the delegated Technical Authority based on the following criteria:

a. Gravitational Environment,
b. Full Mission Duration,
c. Time to receive terrestrial medical capability,
d. Radiation Environment,
e. Spacesuit Capability,
f. Destination,
g. Mission Phase, or
h. Other definable mission parameter.

As per NPR 7120.5, NASA Space Flight Program and Project Management Technical requirements, during the systems requirements phase of program or project development, technical requirements applicability will be determined based on the program's mission parameters. Refer to Figure 1.2-1— Applicability, Tailoring, Verification, and Human Rating/Certification of Flight Readiness of Vehicles, for the process of applicability, tailoring, and verification of requirements for programs or projects.

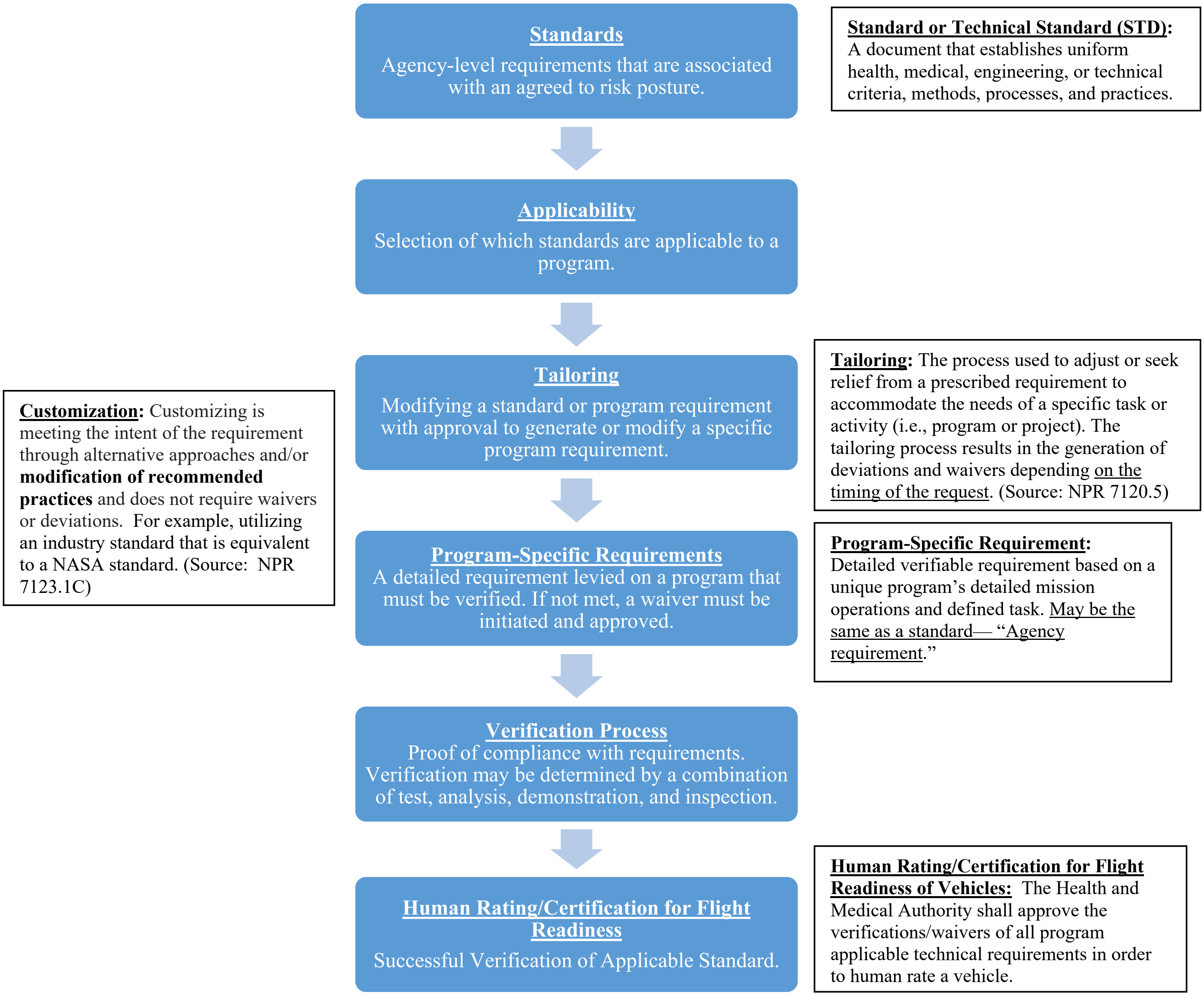


Figure 1.2-1— Applicability, Tailoring, Verification, and Human Rating/Certification of Flight Readiness of Vehicles

1.3 Tailoring

In accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements, tailoring is the process used to adjust or seek relief from a prescribed requirement to accommodate the needs of a specific task or activity (e.g., program or project). Tailoring is both an expected and accepted part of establishing proper requirements. The tailoring of the requirements and associated waivers and deviations from this NASA Technical Standard for application to a specific program or project **shall** be formally documented as part of program or project requirements and require formal approval from the HMTA/OCHMO in accordance with NPR 7120.5.

1.3.1 Full Mission Duration Applicability

In order to protect human health and performance from exposures or conditions that have a cumulative effect, technical requirements will be tailored into program requirements pertaining to the full mission duration (from launch of crew through their landing back on Earth) for each human spaceflight vehicle or habitat which is used to conduct one or more segments of a multi-segment or multi-vehicle mission, even if their isolated segment would have allowed for higher exposures on its own.

Missions may be comprised of consecutive segments that occur in different vehicles, take place in different locations in space with varying distances from Earth, and last for different durations. Many requirements that pertain to cumulative exposures and conditions (such as Permissible Exposure Limits) have been tailored (relaxed) to accommodate short missions occurring in single vehicles. However, for multi-segment or multi-vehicle missions, cumulative exposure over the entire duration of the mission needs to be considered. Exposure in one vehicle that is occupied for a segment of the full mission duration cannot be taken in isolation of the rest of the mission. It is not advisable for each vehicle to maintain its own short duration exposure requirements and expect other vehicles or habitats in the mission to lower their exposure limits to compensate for a higher exposure level in another vehicle. Similarly, a vehicle cannot expect other vehicles within the enterprise to compensate for lack of countermeasures in that vehicle.

1.4 Authority

NASA’s policy for establishing technical requirements to protect the health and safety of crew and for providing health and medical programs for crewmembers during all phases of spaceflight, is authorized by NPD 1000.3, The NASA Organization, and NPD 8900.5, NASA Health and Medical Policy for Human Space Exploration. NPD 8900.1, Medical Operations Responsibilities in Support of Human Space Flight Programs, and NPD 8900.3, Astronaut Medical and Dental Observation Study and Care Program, authorize the specific provision of health and medical programs for crewmembers.

2. APPLICABLE DOCUMENTS

2.1 General

2.1.1 The documents listed in this section contain provisions constituting technical requirements of this NASA Technical Standard as cited in the text.

2.1.2 The latest issuances of cited documents apply unless specific versions are designated.

2.1.3 Use of a version other than as designated must be approved by the delegated Health and Medical Technical Authority.

2.1.4 Applicable documents may be accessed at https://standards.nasa.gov or obtained directly from the Standards Developing Body or other document distributors. When not available from these sources, information for obtaining the document is provided or user should contact the office of primary responsibility or Center Library.

2.1.5 References are provided in Appendix A.

2.1.6 Acronyms, abbreviations, and symbols are provided in Appendix B.

2.1.7 Definitions are provided in Appendix C.

2.2 Government Documents

NASA

HEOMD-003	Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions (https://ntrs.nasa.gov/api/citations/20210024177/downloads/HEOMD-003%20Crewed%20Deep%20Space%20Cert%20Rqmts%20Rev%20A_Post-Final.pdf)
JPR-1880.4	Requirements and Limitations for Exposure to Reduced Atmospheric Pressure
JPR-1800.5	Biosafety Review Board Operations and Requirements
JSC-20584	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants

JSC-26895	Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials (https://www.nasa.gov/sites/default/files/atoms/files/jsc_26895_rev1_final.pdf)
JSC-33124	41-Node Transient Metabolic Man Computer Program Documentation – A thermal regulatory model of the human body with environment suit applications
NASA-STD-3001, Volume 1	NASA Spaceflight Human-System Standard, Volume 1: Crew Health
NASA-STD-5017A	Design and Development Requirements for Mechanism
NASA-STD-8719.27	Implementing Planetary Protection Requirements for Space Flight
NASA/SP-2010-3407	Human Integration Design Handbook (HIDH)
NASA/SP-20210010952	NASA Human Systems Integration Handbook https://ntrs.nasa.gov/citations/20210010952
NASA/TM-2013-217380	Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events
NPD 1000.3	The NASA Organization
NPD 8020.7G	Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (https://nodis3.gsfc.nasa.gov/npg_img/N_PD_8020_007G_/N_PD_8020_007G__main.pdf)
NPR 8705.2	Human-Rating Requirements for Space Systems
NPD 8900.5	NASA Health and Medical Policy for Human Space Exploration
NPR 7120.5	NASA Space Flight Program and Project Management Requirements
NPR 7120.11	NASA Health and Medical Technical Authority (HMTA) Implementation
NPR 7123.1	NASA Systems Engineering Processes and Requirements

SLS-SPEC-159	Cross-Program Design Specification for Natural Environments (DSNE)

Federal

49 CFR Part II, Parts 213 and 238	Department of Transportation, Federal Railway Administration: Vehicle/Track Interaction Safety Standards; High-Speed and High Cant Deficiency Operations; Final Rule March 13, 2013

2.3 Non-Government Documents

American Conference of Governmental Industrial Hygienists (ACGIH)

ACGIH	Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®) Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices (www.acgih.org/)

American National Standards Institute (ANSI)

ANSI C78-377 (see NEMA C78.377)	Electric Lamps - Specifications for the Chromaticity of Solid-State Lighting (SSL) Products
ANSI/ASA S2.70 (2006)	Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand
ANSI/ASA S3.2 (2009) (see LIA Z136.1)	Method for Measuring the Intelligibility of Speech over Communications Systems
ANSI LIA Z136.1 (2014)	American National Standard for Safe Use of Lasers

American Society for Testing and Materials (ASTM) International

ASTM C1057-17	Standard Practice for Determination of Skin Contact Temperature
ASTM F2291-18, ASTM F2291-20	Standard Practice for Design of Amusement Rides and Devices

Illuminating Engineering Society (IES)

IES TM-30	Method for Evaluating Light Source Color Rendition

Institute of Electrical and Electronics Engineers (IEEE)

IEEE C95.1™	IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

International Electrotechnical Commission (IEC)

IEC/TR 60479	Effects of current on human beings and livestock
IEC 60601	Medical Electrical Equipment

International Organization for Standardization (ISO)

ISO 2631-1:1997	Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements, Annex B and Annex D
ISO 20283-5	Mechanical vibration—Measurement of vibration on ships; Part 5 - Guidelines for measurement, evaluation and reporting of vibration with regard to habitability on passenger and merchant ships
ISO 7731:2003(E)	Ergonomics -- Danger signals for public and work areas -- Auditory danger signals

2.4 Order of Precedence

2.4.1 The requirements and standard practices established in this NASA Technical Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation.

2.4.2 Conflicts between this NASA Technical Standard and other requirements documents will be resolved by the delegated Technical Authority.

3. SYSTEMS ENGINEERING PROCESSES

Methods for incorporating an understanding of human capabilities, limitations, and functions (including ill, injured, and deconditioned states) are to be described in an implementation process resulting in performance technical requirements. This strategy ensures that human performance is consistently addressed with system performance throughout the system life cycle and that the design is informed and enhanced by evaluations of human performance-related risks and considers human integration at all levels of the system, from individual components to the level of the complete integrated system.

3.1 Systems Engineering Processes

This NASA Technical Standard is tightly linked with NPR 7123.1B, NASA Systems Engineering Processes and Requirements, and NPR 8705.2. NPR 7123.1 requires a human-centered design (HCD) process along with a Human Systems Integration Plan (HSIP). The HCD process is characterized by task analysis, prototyping, early user involvement, and iterative, developmental human-in-the-loop (HITL) testing. The HSIP includes guidance for implementing and integrating human considerations into the system acquisition and development processes to enhance human system design, reduce life-cycle ownership cost, and optimize total system performance. NASA HSI domains include human factors engineering, operations, safety, training, maintainability and supportability, and habitability and environment. These six NASA HSI domains are considered concurrently and integrated with all other systems engineering design activities. NPR 8705.2 requires the program/project to establish a human-systems integration team to support the implementation of the HSIP. NASA-STD-3001 extends human-centric design and HSI as outlined in NPR 7123.1 NASA Systems Engineering Processes and Requirements and NPR 8705.2 Human-Rating Requirements for Space Systems.

3.2 Human-Centered Task Analysis

[V2 3006] Each human spaceflight program or project **shall** perform a human-centered task analysis to support systems and operations design.

[Rationale: A task analysis is a methodical and iterative process that analyzes tasks allocated to the human by decomposing individual tasks into simpler actions (task steps) and identifying the task parameters and conditions that can either enable or constrain human interface interactions, including identification of information required to perform the task. The focus of the task analysis is on the human and how they interact, both physically and mentally, with the hardware, software, procedures, and other users of the system to perform the tasks. It spans all mission phases and includes nominal, maintenance, contingency, and emergency operations. A task analysis may be performed for any human interaction with the system and is not restricted to flight crew.

The task analysis can be initiated as early as the Concept and Technology Development phase, when baseline mission concepts, requirements, technologies, and the human role are being defined. As design concepts are iteratively evaluated and matured, task definitions are refined.

By the critical design phase, the task analysis should be a mature product. A task analysis can be iteratively updated after the critical design phase and even after certification to reflect changes in design or operational use between missions. Task analysis can be used in the development or identification of gaps in requirements. The analysis is used to drive design, developmental human-in-the-loop (HITL) evaluation, and verification efforts for task effectiveness, efficiency, satisfaction and safety. It also informs the development of human error analysis, operational procedures, and training. Task analysis is critical to the implementation and verification of numerous other technical requirements. For more information, see 4.1 in the HIDP.

Task analysis will be updated and delivered throughout the development lifecycle as contractual data requirements in Statements of Work, Data Requirements Documents (DRDs), Data Procurement Documents (DPDs), joint or multilateral agreements, and/or relevant Verification Closure Notices (VCNs).]

3.3 Human Error Analysis

[V2 3102] Each human spaceflight program or project **shall** perform a task-based human error analysis (HEA) to support systems and operations design.

[Rationale: HEA is a systematic approach to evaluate human actions and identify potential human error, consequences, and mitigations. Potential human errors include inadvertent operator actions, failure to perform an action, performing a wrong action, performing an action incorrectly, and performing an action with incorrect timing. The intent of the HEA is to identify human error and apply the appropriate error management to mitigate its effect on the system by designing the system according to the following precedence: (1) prevent the error, (2) reduce the likelihood of the error and provide the capability for detection in time to correct and recover, and (3) limit the negative effects of the error.

HEA spans all mission phases and includes nominal, contingency, and emergency operations, including ground operations when crew is present. It includes interactions with hardware, software, procedures, and other users of the system. Since the number of tasks associated with a system's operation and maintenance can be immense, the HEA should focus on those tasks, as defined by task analysis and safety hazard analyses, that are most important to mission success, starting with those that could result in catastrophic failure.

The HEA is used to identify and mitigate error traps in design and assist in scoping the selection of task sequences and scenarios for human-in-the-loop (HITL) verification testing. The HEA will be updated and delivered throughout the development lifecycle as contractual data requirements in either Statements of Work, Data Requirements Documents (DRDs), Data Procurement Documents (DPDs) and/or Verification Closure Notices (VCNs). A summary of the human error analysis performed and how the results influenced the system design is required to be included in the Human Error Analysis Summary Report in the Human Rating Certification Package at each lifecycle milestone design review.]

3.4 Iterative Developmental Testing

[V2 3101] Each human spaceflight program or project **shall** perform iterative human-in-the-loop (HITL) testing throughout the design and development cycle.

[Rationale: As a key component of the HCD process as defined in Human Integration Design Process (NASA/TP-2014-218556) and the HSI process as defined by the NASA Human Systems Integration Handbook (NASA/SP-20210010952), iterative testing is an important method for identifying issues early, when changes are affordable and feasible. It is a structured way to mature the design and to track readiness for verification. Iterative human-in-the-loop (HITL) testing is required throughout the design and development cycle to identify issues related to usability, operability, workload, situation awareness, display design, and commonality. Test report products and evidence of the influence of outcome on design are to be delivered throughout the development lifecycle as contractual data requirements in the Statement of Work, Program and Design Milestone entry and exit criteria, or Data Procurement Documents. A summary of HITL usability evaluations for human-system interfaces, integrated human-system performance testing to date, and how the results influenced the system design is required to be included in the Human Rating Certification Package at each lifecycle milestone design review.]

4. PHYSICAL CHARACTERISTICS AND CAPABILITIES

A systems engineering process that adequately considers human performance variability and limitations during spacecraft design, development, testing, and evaluation is of critical importance to the health, safety, and performance of flight crews, as well as to the protection of hardware and systems. As with any other system component, there are limits to human capabilities. The conditions encountered during spaceflight can degrade human capabilities. These performance-limiting conditions may include environmental factors such as weightlessness and g-transitions, physiological effects such as space sickness and spatial disorientation, and other factors such as confinement and protective clothing.

The human performance envelope is bounded by physical as well as cognitive limitations. Accommodating these limitations during spaceflight is critical to all aspects of mission success, including the maintenance of crew health and safety.

Physical characteristics and capabilities include body dimensions, range of motion, mass, volume, surface area, and strength. It is important that the design of equipment, including vehicles, spacesuits, and other interfaces, accommodates the physical characteristics of the entire user population. Adjustments for the effects of external factors such as gravity environments, clothing, pressurization, and deconditioning related to mission duration are to be included in the design.

A system designed for human use or habitation must accommodate the range of human characteristics and capabilities relevant to the system and operating environment for the NASA-defined crew population. Datasets are provided that include characteristics and capabilities for anthropometric dimensions, range of motion, strength, mass, volume, and surface area. The datasets and their supplemental information in Appendix E, Physical Characteristics and Capabilities, take into account human characteristics such as age, sex, and physical condition as well as mission characteristics such as clothing and suit pressurization.

4.1 Physical Data Sets

4.1.1 Functional Anthropometric Accommodation

[V2 4102] The system **shall** ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix E, Physical Characteristics and Capabilities, Sections E.2 and E.3.

[Rationale: All crewmembers need to be able to perform any planned tasks efficiently and effectively. Physical crew interfaces need to be located within the visible and functional reach limits of the worst case (i.e., most limited) crewmember in his/her working posture using the most encumbering equipment and clothing anticipated. Design constraints may dictate layouts or tasks that force a crewmember to move, twist, or stretch into awkward positions. However, the system design must not require the crewmember to achieve ranges of motion outside those

defined in Appendix E. When applied to suit design, the suit must allow an unpressurized and pressurized suited crewmember to achieve the entire range of motion defined in the appendix. The suit must be designed to allow for suited crewmembers to operate in an independently designed vehicle or habitat, and the vehicle or habitat must not require a range of motion a suit cannot provide.

A task analysis that identifies hardware interfaces and obstructed/confined/restrained reaches for planned tasks is used with Appendix E to define critical anthropometric dimensions and ranges of motion and provide design considerations for crew interfaces. The task analysis also identifies other parameters and constraints (e.g., mission phase, recumbent postures, etc.) that may require adjustments to the anthropometric data in the Appendix. Guidance on the evaluation of design for anthropometry and range of motion can be found in section 4.1 of OCHMO-HB-004, Anthropometry, Biomechanics, and Strength.

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets, which provide the most frequently used values in standard reference postures. When a design requires a posture outside of the standard reference posture, such as rotation from upright to recumbent seating, minimum and maximum values for the new posture must be developed for the unique design posture.

Identification of a posture, dimension, or range of motion not provided in the table needs coordination and concurrence from NASA Stakeholders. When a system must accommodate a suited crewmember, an additional suited dataset can be provided that accurately identifies suited human dimensions. A tailored data set may be provided by NASA based on program or mission specific criteria, especially when a specific spacesuit has been identified.]

4.1.2 Body Mass, Volume, and Surface Area Data

[V2 4103] The system **shall** accommodate the body characteristic data for mass, volume, and surface area as defined in Appendix E, Physical Characteristics and Capabilities, Sections E.4, E.5, and E.6.

[Rationale: Depending on mission or design requirements, system developers could need body mass, volume, and body surface area data that accurately describe the entire size range of potential crewmembers.

Surface area data could be needed when assessing radiation exposure or designing a body contact cooling system. Volume data may be needed for center of gravity or buoyancy calculations.

Body mass data can describe both whole body mass and body segment mass. In addition to simple body mass, data includes centers of gravity and moments of inertia. Body mass data is important for multiple systems. Propulsion and dynamic systems calculations depend on accurate data of crewmember mass to size hardware systems and design proper vehicle dynamic controls. Body mass data is used to characterize forces exerted between crewmembers and *equipment such as body support systems (e.g., seats, brackets, and restraints) under all anticipated acceleration and gravity environments. Body segment centers of gravity may be an important design consideration for crewmember balance and stability during dynamic mission phases or for understanding how loads are distributed during acceleration. Guidance on the evaluation of design using body characteristic data can be found in NASA/TP-2014-218556, Human Integration Design Process (HIDP).*

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of body characteristic data not provided in the table needs coordination and concurrence from NASA Stakeholders. A tailored set may be provided by NASA based on program or mission specific criteria.]

4.1.3 Crew Strength

All crewmembers need to be able to perform any planned tasks efficiently and effectively, without risk of injury and without undue concern of the hardware sustaining damage. Human-System Interfaces need to accommodate both the minimum and maximum anticipated strength of potential crewmembers. Strength refers to a person's ability to generate force. The system must withstand the load that is imparted and must not require excessive forces to operate.

4.1.3.1 Crew Operational Loads

[V2 4104] The system **shall** be operable by crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, with the lowest anticipated strength as defined in E, Physical Characteristics and Capabilities, Section E.7.

[Rationale: All crewmembers need to be able to perform any planned tasks efficiently and effectively. The crew operating load data in Appendix E defines the lowest anticipated forces that can be applied by crewmembers in unsuited, suited-unpressurized, and suited-pressurized conditions, taking into account deconditioning and factors of safety for critical tasks. A task analysis that identifies planned crew tasks, hardware interfaces, expected postures, and task criticality, frequency, and duration is used with Appendix E to define the maximum acceptable value for actuation and continued operation of hardware interfaces. Guidance on the evaluation of design using crewmember strength data can be found in NASA/TP-2014-218556, Human Integration Design Process (HIDP).

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of postures or forces not provided in the table needs coordination and concurrence from NASA Stakeholders. A tailored data set may be provided by NASA based on program or mission specific criteria.]

4.1.3.2 Withstand Crew Loads

[V2 4105] The system **shall** withstand forces imparted by the crew during all phases of flight, including but not limited to prelaunch, ascent, orbit, entry, and postlanding, as defined in Appendix E, Physical Characteristics and Capabilities, Section E.7 without sustaining damage.

[Rationale: Vehicle hardware are to be designed to withstand large forces exerted by a crewmember during nominal operations without breaking or sustaining damage that would render the hardware inoperable. Additionally, crew may exert high forces when operating controls in emergency situations, such as attempting to open a hatch for emergency egress. The resulting damage to equipment could make it impossible to respond safely to the emergency. To avoid overdesign, a task and error analysis which defines planned crew tasks, hardware interfaces, expected postures, and task criticality is used to identify which interfaces must tolerate maximum crew operational loads. This includes identifying critical hardware that may be inadvertently used as a mobility aid or restraint. Guidance on the evaluation of design using crewmember strength data can be found in NASA/TP-2014-218556 Human Integration Design Process (HIDP); information on task analysis process can be found in Section 4.1. Durability of the Structural Integrity of Hardware Due to Unintentional Crew Forces is addressed in [V2 9027] Protect Crew and Equipment.

The intent of this requirement is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of postures or forces not provided in the table needs coordination and concurrence from NASA Stakeholders. A tailored data set may be provided by NASA based on program or mission specific criteria.]

4.2 Muscle Effects

[V2 4013] The effects of muscle endurance and fatigue **shall** be factored into system design.

[Rationale: Tasks with high force requirements and repetitive tasks (even with low force requirements) can cause fatigue. The crew task analysis is to identify factors that can lead to overexertion or fatigue such as task frequency, duration, repetitive motions, high forces, current and previous gravity environments and duration, suit configuration, etc. The applicable factors are needed for NASA to provide an appropriate strength dataset and they should be considered in designs for crewmember operation. Apollo EVA crew and some recent ISS EVA crews reported forearm muscle fatigue, some lasting after EVA mission day, due to repetitive force exertion to grasp and manipulate items while wearing pressurized gloves. The issue was exacerbated by the design of the gloves having fingers that returned to extended position rather than neutral, curved position requiring the crew to exert additional, unproductive movement and force. The effects of muscle fatigue may be mitigated through task design that includes providing mechanical aids, recovery rest periods, or varies the use of muscle groups.]

4.3 Aerobic Capacity

[V2 4015] The system **shall** be operable by crewmembers with the aerobic capacity as defined in NASA-STD-3001, Volume 1.

[Rationale: An individual's aerobic capacity determines the ability to perform a task at a given level of work. The aerobic capacity in conjunction with the operational concept provides an upper bound for oxygen (O_2) demand, carbon dioxide (CO_2) production, heat rejection requirements, etc. This information is vital for all spacecraft Environmental Control and Life Support System (ECLSS) designs, including the extravehicular activity (EVA) suits. This information helps to determine the sizing of the primary and emergency O_2 systems, scrubbers, etc., and help engineers perform trade studies on various designs based on the operational scenarios and metabolic expenditure.]

5. HUMAN PERFORMANCE AND ERROR

In addition to the physical capabilities and limitations discussed in Chapter 4, system design must accommodate human visual, auditory, sensorimotor, and cognitive capabilities and limitations to support effective and efficient human performance. These capabilities and limitations vary with age, sex, and fatigue, and are further impacted by the environmental conditions of spaceflight. Determination of anticipated levels of crew capability and anticipated levels of task demands can be made through a detailed task analysis.

- ***Visual capabilities*** *include visual acuity, spatial contrast sensitivity, visual accommodation, field of regard, color discrimination, stereoscopic depth perception, and temporal contrast sensitivity. These capabilities apply to displays and controls, as well as other visual observations, such as out-the-window viewing.*

- ***Auditory capabilities*** *include, at a minimum, absolute threshold of hearing, auditory localization, and speech intelligibility. Audio-communications can play an essential role in completing mission operations.*

- ***Sensorimotor capabilities*** *include balance, locomotion, eye-hand coordination, visual control, tactile perception, and orientation perception. Controls and displays can provide information to the operator through sensorimotor perception channels.*

- ***Cognitive capabilities*** *include attention, memory, decision making, problem solving, logical reasoning, and spatial cognition. Accommodating cognitive capabilities is important to ensure optimal task performance, teamwork, and crew safety.*

When human capabilities and limitations are considered in design, tasks can be accomplished within time and performance criteria; crew interfaces are legible and usable; cognitive workload levels are appropriate, avoiding underload and overload; and in case of inevitable overload or underload, avoiding scheduling critical tasks for that periods; crew situation awareness is sufficient to detect and respond to hazards; design-induced errors are minimized; and vehicles are controlled with ease and precision. The following human performance requirements support these goals and will provide important evidence that the human-system design supports crew safety and productivity.

For detailed discussions regarding human performance capabilities, e.g., visual perception, auditory perception, cognition, and workload, see chapter 5, Human Performance Capabilities, of the Human Integration Design Handbook (HIDH). For detailed discussions regarding the design of user interfaces, e.g., visual acquisition of displays, visual displays, layout of displays and controls, see chapter 10, Crew Interfaces, of the HIDH.

5.1 Human Performance

5.1.1 Operability

[V2 10003] The system **shall** provide crew interfaces that enable tasks to be performed successfully within the appropriate time limit and degree of accuracy.

[Rationale: Operability is the ability of the intended user to achieve the required or desired outcome, within the planned or required time to effect, using the system and procedures as designed. Successful task performance within the appropriate completion time is an objective measure of design effectiveness. Ineffective design may directly or indirectly impact operational timelines, crew stress and behavioral health, or safety. Design for operability is guided by function and task analysis, iterative design, and human-in-the-loop (HITL) evaluation. The task analysis will define tasks where timing is critical, as well as the performance outcome parameters.]

5.1.2 Usability

[V2 10001] The system **shall** provide crew interfaces that result in an average satisfaction score of 85 or higher of the NASA Modified System Usability Scale (NMSUS).

[Rationale: Systems that are usable are acceptable and operable by the intended user for performing expected tasks. If a design does not meet the users' needs, expectations, intuitions, or capabilities, and as a result causes frustration or confusion, the design is not effective. Ineffective design may directly or indirectly impact operational timelines, crew stress and behavioral health, or safety. Errors may occur, tasks may take longer to complete, or users may abandon, work around, or choose not to perform the tasks. Design for perceived crew acceptability is guided by task analysis and iterative prototyping and evaluation. Human-in-the-loop acceptability evaluation is conducted early and throughout system design to gather user feedback on design effectiveness, efficiency, and potential design-induced errors to influence design improvements and measure design progress. While many tools exist for assessing user acceptability, NASA recommends use of the NMSUS with participants that have been trained on the tasks and system design to a pre-set performance criterion throughout design development. NMSUS is a reliable instrument that is short and easy to administer and is valuable for eliciting feedback on specific design elements for iterative improvement. The NMSUS scale and information on scoring can be found in Figure 5.1-1—NASA Modified System Usability Scale (NMSUS).]

NASA Modified System Usability Scale (SUS) - NMSUS					
	Strongly Disagree 1	2	3	4	Strongly Agree 5
1. I thought the system was easy to use.	○	○	○	○	○
2. I think that I would need technical support to be able to use this system.	○	○	○	○	○
3. I found the various functions in this system were well integrated.	○	○	○	○	○
4. I thought there was too much inconsistency in this system.	○	○	○	○	○
5. I imagine that most trained crewmembers would learn to use this system very quickly.	○	○	○	○	○
6. I found the system very cumbersome to use.	○	○	○	○	○
7. I felt very confident using the system.	○	○	○	○	○
8. I needed a lot of training on this system in order to get going.	○	○	○	○	○
Scoring *The NMSUS is scored using the following equation, which is based on SUS (see Lewis & Sauro, The Factor Structure of the System Usability Scale):* *NMSUS = 3.125 * ((Q1-1)+(5-Q2)+(Q3-1)+(5-Q4)+(Q5-1)+(5-Q6)+(Q7-1)+(5-Q8))*					

Figure 5.1-1—NASA Modified System Usability Scale (NMSUS)

5.1.3 Design-Induced Error

[V2 10002] The system **shall** provide crew interfaces that do not exceed the maximum observed error rates listed in Table 5.1-1—Maximum Observed Design-Induced Error Rates.

[Rationale: Errors are detrimental to crew effectiveness, efficiency, acceptability, and safety. Even when recoverable or resulting in minimal impact, errors can still negatively impact crew performance in terms of productivity and satisfaction. Errors are defined as an action that does not result in the intended outcome or a failure by the crew to perform an action within the required limits of accuracy, sequence, or time which results in unwanted consequences. Design-induced errors include but are not limited to: missed or incorrect inputs or selections, display navigation errors, errors due to inadequate hardware component design, errors due to lack of system feedback to user inputs, errors due to inadequate information, errors due to design inconsistency or unfamiliar terminology, and the inability to complete a step or task. Unintentional errors that are related to human reliability (e.g., bumping a control due to fatigue) are not considered design-induced errors.

It is crucial for design to be guided by an iterative, human-centered design process including task analysis, human error analysis, and human-in-the-loop (HITL) evaluations. Task analyses identify user tasks and task sequences. To ensure crew have situation awareness, detailed analysis of information needs are performed to identify the needed information is presented in *the context necessary for crew to perform the correct actions at the correct time. Human error analysis identifies potential user errors at each step and the outcome or system consequence if the error is committed. Task errors that could result in a catastrophic hazard should be prevented through careful interface design and thorough evaluation. Tasks that are identified as complex, leading to critical or catastrophic hazards/events, or frequent need more rigorous developmental testing and are to be included in HITL verification testing.*

For purposes of HITL testing, a scenario requiring evaluation will be defined as an activity driven by one or more related and sequential procedures. The procedure consists of a series of task steps, where a task step will be defined as a single instruction to the test subject, as is typical of current spaceflight procedures. Participants will maintain task completion times commensurate with the performance requirements.

- *If any errors classified as having the potential of leading to a catastrophic outcome occur, the root cause of the error must be identified, mitigated satisfactorily (approved by NASA), and a re-test of the task performed to prove that the error has been eliminated.*
- *The percentage of errors (erroneous task steps) for each user is calculated by dividing the number of erroneous task steps and incomplete task steps by the total number of task steps and multiplying the result by 100.*
- *The percentage of users committing each error (erroneous task step) is calculated by dividing the number of users committing each erroneous task step by the total number of users and multiplying the result by 100.]*

Table 5.1-1—Maximum Observed Design-Induced Error Rates

Type of Error	Maximum Observed Error Rate
Catastrophic Error	0%
Non-Catastrophic Errors per User per Task	5%
Non-Catastrophic Errors per Step per Task	10%

5.1.4 Cognitive Workload

[V2 5007] The system **shall** provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for tasks performed under degraded system conditions.

[Rationale: Cognitive workload is the users' perceived level of mental effort that is influenced by many factors, particularly task load and task design. Acceptability of cognitive workload level for critical or frequent operations/task sequences should be measured using a validated workload scale such as the Bedford Workload Scale. On the Bedford scale, acceptable level of workload is a rating of 3 or less for critical, novel, or frequent tasks. For tasks that are performed during cases of degraded system performance where there is a failure state that directly impacts the tasks being performed, ratings of 6 or less are allowed. The workload

measurement enables standardized assessment of whether temporal, spatial, cognitive, perceptual, and physical aspects of tasks and the crew interfaces for these tasks are designed and implemented to support each other. Application of workload measurement for crew interface and task designs in conjunction with other performance measures, such as usability and design-induced error rates, helps assure safe, successful, and efficient system operations by the crew. Workload levels may be modulated (raised or lowered) through the combination of user-interface design and task design (e.g., task simplification, subtask combination and sequencing, and the distribution of tasks among multiple crewmembers and between crew and automation).]

5.1.5 Physical Workload

[V2 10200] The system **shall** provide crew interfaces that result in a Borg-CR10 rating of perceived exertion (RPE) of 4 (somewhat strong) or less.

[Rationale: The design of interfaces for physical tasks is important because of the risks of musculoskeletal injuries and disorders that arise out of mismatch between a crew capability and the physical demands of their task. Minimizing these risks is especially important for spaceflight where schedule and specialized crew training for unique tasks and environments cannot easily be adjusted. Attention should be paid to design of tasks that are high effort, extended duration, or involve repetitive motions that can result in over-exertion or fatigue, such as suit donning or doffing and EVAs. To ensure task and interface designs result in acceptable levels of physical workload, human-in-the-loop evaluation should be conducted early and throughout system design to gather user feedback on perceived exertion and task performance. Verification testing using the Borg RPE scale includes tasks that are suspected to be physically demanding and not those that are primarily cognitive tasks (unless they also include a significant physical aspect). The Borg RPE is a useful tool for measuring an individual's effort and exertion, one with decades of use and validation that was designed to scale with workload intensity and heart rate during the execution of physical work (Borg, Gunnar. "Psychophysical scaling with applications in physical work and the perception of exertion." Scandinavian journal of work, environment & health (1990): 55-58.).]

5.1.6 Situation Awareness

[V2 5006] Systems **shall** provide the Situation Awareness (SA) necessary for efficient and effective task performance and provide the means to recover SA, if lost, for anticipated levels of crewmember capability and anticipated levels of task demands.

[Rationale: SA refers to the process and outcome of understanding the current context and environment, evaluating that situation with respect to current goals, and projecting how that situation will evolve in the future.

Lack of SA has been associated with numerous accidents and incorrect decisions by flight crews in commercial aviation and in ground-based simulation of spacecraft operations. To maximize SA and optimize operational accuracy and efficiency, designers are to perform a detailed information requirements analysis of all onboard operations and ensure that the crew-vehicle *interfaces provide all required information to perform the operation. A useful and effective system design supports the crewmember's ability to rapidly and accurately assess the current situation. Occasional loss of SA is expected in an operational setting where crew may have to unexpectedly move from task to task as events demand. It is important that the system design provides the necessary information, cues, or indicators to help the crewmember easily recover SA. Determination of anticipated levels of crew capability and anticipated levels of task demands is based on a detailed task analysis. SA can be directly assessed with a variety of validated industry tools (e.g., Situation Awareness Global Assessment Technique (SAGAT), Situation Awareness Rating Technique (SART)) and indirectly assessed through the measurement of usability, cognitive workload and design-induced error.]*

5.1.7 Legibility

[V2 5051] The system **shall** provide crew interfaces that are legible under expected operating conditions.

[Rationale: Information presented to crew must be legible in all planned operating locations and conditions. Legibility includes both text elements and meaningful graphic elements such as symbols, icons, and maps and is important for the timely and accurate processing of information. Legibility depends upon display properties such as resolution and contrast, text properties such as font color, size, and contrast with background color and texture, visual capabilities of the operator, worksite illumination, and glare. In addition, the possible viewing angles, distance of the operator, the presence of a helmet or visor in a suit, and expected environmental operating conditions during use (e.g., high acceleration and vibration) need to be considered.]

5.1.8 Controllability and Maneuverability During Manual Control (Handling Qualities – Level 1)

[V2 10004] The spacecraft **shall** exhibit Level 1 handling qualities (Handling Qualities Rating (HQR) 1, 2 and 3), as defined by the Cooper-Harper Rating Scale, during manual control of the spacecraft's flight path and attitude when manual control is the primary control mode or automated control is non-operational.

[Rationale: Handling qualities are defined as "those qualities or characteristics of [dynamic vehicle control] that govern the ease and precision with which a [user] is able to perform the tasks required" (Cooper and Harper, 1969). The Cooper-Harper rating scale is a standard method for measuring handling qualities. See Figure 5.1-2—Cooper-Harper Handling Qualities Rating Scale.

Level 1 handling qualities are the accepted standard for manual control of flight path and attitude in military aircraft. Level 1 handling qualities will allow the crew to effectively control the spacecraft when necessary for mission completion or to prevent a catastrophic event. "Non-operational" is defined as automated control system failed or manually disabled. Note that there are numerous vehicle performance factors that can significantly affect handling qualities, with two well documented factors including control and display latency. If the inception of a *controller and the pilot's observation of its system response occur with a significant latency, it is difficult to identify whether the operation of the control had the intended effect within sufficient time constraints, leading to adverse handling qualities and possibilities of adverse outcomes such as pilot-induced oscillation. Control latencies of less than 100ms for high gain tasks, and less than 200ms for low gain tasks, are associated with Level 1 Handling Qualities. High gain tasks are those for which temporal demands and task urgency are key drivers of task success or failure, while low gain tasks are those which place lower temporal demands on the crew (Reference MIL-STD-1797A Notice 3 - Flying Qualities of Piloted Aircraft, 2004). Display related information used in vehicle piloting tasks, including translation and rotation, also affect handling qualities. Display system latencies in the range of 50-100ms are associated with Level 1 handling qualities. Display system latency is defined as the time delay between the change in vehicle dynamics and the representation of associated new information on the display (total time from sensors to data presentation on the display). This is required to ensure piloting display elements that translate or rotate will do so smoothly without distracting or objectionable jitter, jerkiness, or ratcheting effects (Reference Funk, et al., 1993, Primary display latency criteria based on flying qualities and performance data). Additionally, if latencies (either control or display) exist that are not consistent and are highly variable during the execution of a task, it can be extremely difficult for crew to mitigate or adapt to the effects of such delays as the inconsistency makes adaptation difficult, resulting in poor handling qualities. A handling quality-related task is defined as the manual control capability that is being rated with the Cooper-Harper Rating Scale. Each task within a scenario is rated separately and has to meet the appropriate Level 1 handling qualities (handling quality ratings of 1, 2, or 3). Reference NASA-TN-D-5153, The use of pilot rating in the evaluation of aircraft handling qualities, for the Cooper-Harper Rating Scale.]*

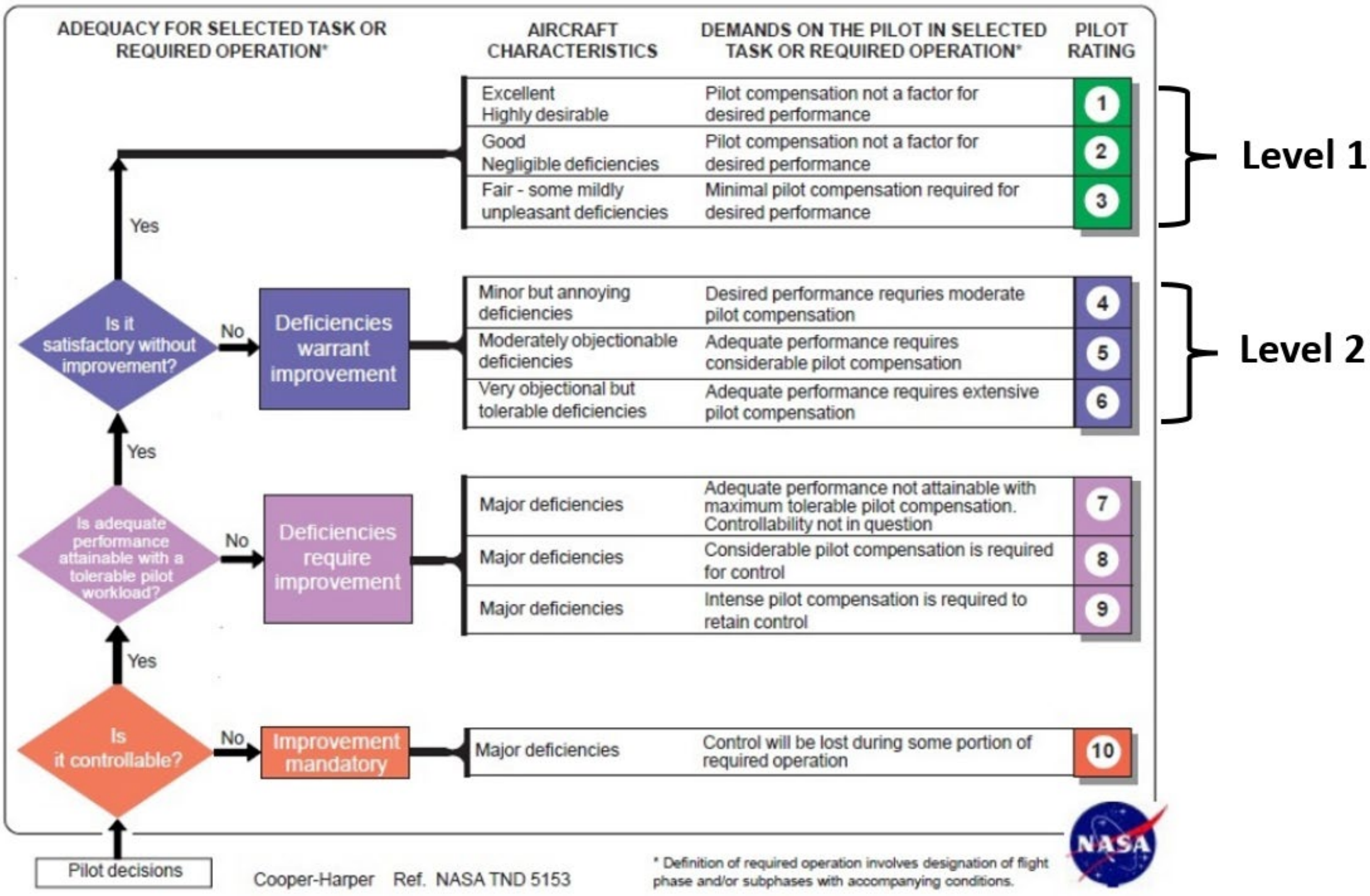


Figure 5.1-2—Cooper-Harper Handling Qualities Rating Scale

5.1.9 Controllability and Maneuverability During Manual Control with Deficiencies (Handling Qualities – Level 2)

[V2 5052] The system **shall** exhibit Level 2 (HQR 4-6) or better handling qualities during manual control in all other scenarios not specified in [V2 10004] Handling Qualities – Level 1.

[Rationale: Level 2 handling qualities are acceptable when failures of the flight control systems and/or displays and controls, prevent them from functioning as designed for nominal operations. If a failure exists that only affects automation, then Level 1 handling qualities are still expected. Select manual control scenarios that have to meet Level 1 handling qualities will be defined and scoped with applicable program/project agreement. A scenario includes one or more handling quality-related vehicle control tasks performed during a flight phase under specified conditions. Reference NASA-TN-D-5153, The use of pilot rating in the evaluation of aircraft handling qualities, for the Cooper-Harper Rating Scale as captured in Figure 5.1-2—Cooper-Harper Handling Qualities Rating Scale.]

5.2 Human Error

5.2.1 Controls for Human Error

[V2 5053] The system **shall** control for human error according to the following precedence:

a. Design the system to prevent human error in the operation and control of the system.

b. Design the system to reduce the likelihood of human error and provide the capability for the human to detect and correct or recover from the error.

c. Design the system to limit the negative effects of the error.

[Rationale: Human error is an action that is not intended or desired by the operator or a failure on the part of the operator to perform a prescribed action within specified limits of accuracy, sequence, or time that fails to produce the expected result and has led or has the potential to lead to an unwanted consequence. Potential human errors include inadvertent/unintended operator actions, failure to perform an action, performing a wrong action, performing an action incorrectly, and performing an action with incorrect timing. The intent of this requirement is to identify potential human errors that can cause a catastrophic event by predictive human error analysis, determine the appropriate level of tolerance via integrated human error and hazard analyses, and determine the specific controls to mitigate error that could lead to a catastrophic event according to the described precedence.]

5.2.2 Protect Against Inadvertent Activation

[V2 10027] The system **shall** protect against inadvertent activation of controls.

[Rationale: Inadvertent crew actions and loose or uncontrolled movement of hardware could result in unintended activation of controls and cause undesired effects on the system and potentially hazardous consequences. For this requirement, a control is a device or interface that is used to send a command to the system or operate a component. Guards, covers, physical separation from other controls and requiring two operator actions are examples of methods to protect against inadvertent activation. Protections are to be provided for nominal and off-nominal controls, including those used in response to failures and aborts.]

5.2.3 Error Detection and Recovery

[V2 10028] The system **shall** provide the capability to detect and recover from human error and inadvertent changes in system status.

[Rationale: Not all human error or inadvertent input can be prevented. When the system is unable to prevent the error, it is to provide a method that allows the system or operator to detect and recover without the error resulting in a catastrophic event. Incorrect control inputs are from

unintended actions that were able to defeat the design protections and from scenarios where the operator chooses the wrong action forward due to lack of incorrect information and/or poor situation awareness. Detection methods include alerts provided within time to effect and recovery mechanisms include the ability for operators to reverse a previous command or send a new command to correctly address the hazard. Detections and recovery capabilities are to be provided for nominal and off-nominal scenarios, including responses to systems and aborts.]

6. NATURAL AND INDUCED ENVIRONMENTS

Natural and induced environmental factors include air, water, contamination, acceleration, acoustics, vibration, radiation, and temperature. Environmental design factors that can enhance human performance such as crew station layout and lighting are discussed in section 8, Architecture, in this NASA Technical Standard. Overall, the system's environment is to be compatible with tasks to be performed and promote crew health and performance.

6.1 Trend Analysis of Environmental and Suit Data

[V2 6001] The system **shall** provide environmental and suit monitoring data in formats compatible with performing temporal trend analyses.

[Rationale: Requirements are to consider all environmental and suited parameters that may require trend analysis for a given mission. Trending of environmental parameters such as internal atmosphere constituents, temperature, humidity, water, acoustics, radiation, acceleration and dynamic loads, suited biomedical data and suit data (i.e. suit temperature, suit humidity level, suit pressure, ppO_2, $ppCO_2$, metabolic rate and trends of these data points) (see sections 6 and 11 in this NASA Technical Standard for the detailed requirements) is necessary for both anticipating harmful conditions before they occur and troubleshooting using previously stored data. To properly trend, aspects of the data such as the measurement rate are also to be considered, as some parameters may otherwise only be measured infrequently.]

6.2 Internal Atmosphere

A safe, breathable atmosphere is critical to human health and performance. Early identification of potential air quality issues enables mitigation by design. Monitoring atmospheric quality and evaluating trends are essential. The system is to be robust enough to control or allow crew control of atmospheric pressure, humidity, temperature, ventilation flow rate, airborne particulates, partial pressure of O_2 (ppO_2), partial pressure of CO_2 ($ppCO_2$), and trace contaminants within ranges necessary to maintain task performance and human health and safety. Although the following requirements address these components individually, they must be considered as a whole because they are dependent on each other. Additional information about the interplay among internal atmosphere components and the effects on the human is available in section 6.2 of the Human Integration Design Handbook (HIDH). An iterative process should be employed to integrate the human system internal atmospheric limits into the design process, ensuring optimization of the design to afford the most protection possible, within other constraints of the vehicle systems. Atmospheric requirements specific to suited operations can be found in section 11.1, Suit Design and Operations, in this NASA Technical Standard.

6.2.1 Atmospheric Constituents

6.2.1.1 Inert Diluent Gas

[V2 6002] Cabin atmospheric composition **shall** contain at least 30% diluent gas (assuming balance oxygen).

[Rationale: This mitigates clinically significant absorption atelectasis. The choice of diluent gas is dependent on many factors, including physiological activity and contribution to decompression sickness (DCS). The assumption is that the diluent gas will be nitrogen (N_2). Use of helium (He) or argon (Ar) has been considered, but would affect decompression sickness (DCS), thermal and ventilation requirements. Validation and verification of alternate diluent gases must be adjudicated by program medical team and another requirement set be developed. Measurable oxygen absorption atelectasis (lung collapse) occurs with fractions of oxygen above 50%. A diluent gas is required to prevent excessive levels of oxygen absorption atelectasis during prolonged exposures, in addition to reducing the ignition/flammability threshold. Unacceptable risk occurs when breathing less than 20% diluent. Although oxygen absorption atelectasis can be observed in the 25-50% diluent range, clinical and spaceflight experience shows that diluent fractions as low as 25% maintain acceptable levels of pulmonary function for long duration spaceflight activities. Clinically significant atelectasis is unlikely when combining the expected habitat total pressures (typically 8.2 to 14.7 psia) with the hyperoxic bounds established in Table 6.2-1—Inspired Oxygen Partial Pressure Exposure Ranges. Reference [V2 6003] O_2 Partial Pressure Range for Crew Exposure in this NASA Technical Standard for hyperoxic/hypoxic limits.]

6.2.1.2 O_2 Partial Pressure Range for Crew Exposure

[V2 6003] The system **shall** maintain inspired oxygen partial pressure (P_IO_2) in accordance with Table 6.2-1—Inspired Oxygen Partial Pressure Exposure Ranges.

[Rationale: For all systems, the range of ambient dry-gas ppO_2 is to be considered in the context of P_IO_2. Since physiological limits for hypoxic (and hyperoxic) exposure during spaceflight are unknown, systems designed for humans are to be normoxic unless strong rationale is provided for an alternative suggestion. For confined and enclosed spaces at sea level, the Occupational Safety and Health Administration (OSHA) defines oxygen-deficient atmosphere as <19.5% oxygen by volume, and oxygen-enriched atmosphere as >23.5% oxygen by volume (Electronic Code of Federal Regulations, 1910.146(b)(3), current through July 29, 2021) with a correlating normoxic P_IO_2 range between 139-168 mmHg. The OSHA-enriched atmospheric limit is more applicable to material flammability than human hyperoxic limit. Hyperoxia limits are provided to allow needed prebreathe and if necessary, DCS treatment. It is generally accepted that there are no medical or performance issues with constant exposure to one-half an atmosphere of O_2 partial pressure (Clarke, J.M., Oxygen Toxicity [Chapter 6]. The Physiology and Medicine of Diving [4th ed], Bennett, P.B., Elliott, D.H. [eds]. W.B. Saunders Company Ltd: Philadelphia, 1993, pp. 153-69); this is a ppO_2 of 7.35 psia, or 380 mmHg, or as P_IO_2, it is 333 mmHg. NASA operates the extravehicular mobility unit (EMU) at 4.3 psia with

100% O_2, so this is a ppO_2 of 222 mmHg; or as P_IO_2, it would be 175 mmHg, and there are no performance or medical issues to date with this limit. A practical and defensible hyperoxic exposure limit would be a P_IO_2 of 333 mmHg with the assumption that adaptations to microgravity do not modify this terrestrial limit. As far as a hypoxic limit, it has been shown that a mildly hypoxic vehicle system atmosphere as part of a denitrogenation protocol to reduce the risk of DCS is advantageous during spaceflight (e.g., Space Shuttle 10.2 psia/26.5% O_2), as well as recommended by the Exploration Atmospheres Working Group and endorsed by Human Exploration and Operations Mission Directorate (Exploration Atmospheres, HEOMD memo, February 2013). There is no indication on Earth that living and working with chronic P_IO_2 of 127 mmHg degrades health or performance. There are no indications or predictions based on limited past experience that extending exposure time with P_IO_2 of 127 mmHg in micro or partial gravity past 7 days leads to degradation of health or performance in otherwise healthy astronauts. There is no opportunity to collect data in microgravity with P_IO_2 of 127 mmHg to cover the durations of Exploration Class missions, so a health monitoring and mitigation plan is required to implement this condition. These guiding P_IO_2 values may change as further research yields information to better define the physiological limits and acceptable duration for an alternative spaceflight system environment.]

Table 6.2-1—Inspired Oxygen Partial Pressure Exposure Ranges

Inspired O_2 partial pressure $P_IO_2 = (PB - 47) * F_IO_2$				
	Normoxia Target Range	**Indefinite Hyperoxia Upper Limit**	**Short-Term Hyperoxia Upper Limit**	**Mild Hypoxia Lower Limit**
P_IO_2 (mmHg)	145-155	356	791	127****
P_IO_2 (psia)	2.80-3.00	6.89	15.30***	2.46****
Acceptable Duration	Indefinite	Indefinite	6-9 Hours*	Indefinite with monitoring**
Examples	Habitat and Spacesuit Minimum	EVA and Cabin Depress In-Suit Survival	O_2 Prebreathe for EVA Preparation	EVA Preparation (ISS Campout, Shuttle 10.2, Exploration Atmosphere of 8.2 psia and 34% O_2)

PB – Ambient Barometric Pressure (mmHg)
F_I – Fractional concentration of inspired oxygen
F_IO_2 – The dry-gas decimal fraction of ambient O_2
**From Johnson Procedural Requirements (JPR) 1830.6 (Requirements Applicable to Personnel Participating in Diving, Hyper/Hypobaric Chambers, and Pressurized Suit Operations). Page 15, subsection 4.2: Limitations during Oxygen Breathing," shows the limits for prebreathe in a spacesuit. The limit is nine hours when that is the only exposure to enriched O_2 in a 48-hour period. The limit is six hours when it is the only exposure to enriched O_2 in a 24-hour period and also states that consecutive daily exposures are not to exceed five consecutive days.*
***There is no opportunity to collect data in microgravity with P_IO_2 of 127 mmHg to cover the durations of Exploration Class missions, so a health monitoring and mitigation plan are required to implement this condition*
****This P_IO_2 may be exceeded during DCS treatment.*
***** 1-hour time-weighted average with an absolute lower limit for the minimum hypoxia range of 122 mmHg/2.36 psia*

6.2.1.3 Nominal Vehicle/Habitat Carbon Dioxide Levels

[V2 6004] The system **shall** limit the average one-hour CO_2 partial pressure ($ppCO_2$) in the habitable volume to no more than 3 mmHg.

[Rationale: Achieving this level is dependent on individual and total crew generation of CO_2 for all planned activities (factoring in metabolic rates and respiratory quotient), appropriate CO_2 scrubbing and adequate ventilation flow rates to ensure that no localized pockets of CO_2 are generated throughout the habitat. Considerations from other payloads that generate CO_2 are to be taken into account of these totals.

Note: Off-nominal CO_2 values are not included within this NASA Technical Standard due to the unique circumstances of each mission (expected human performance, duration of exposure, access to medical care, etc.) and will be derived as a lower-level program/project requirement.]

6.2.2 Atmospheric Pressure

6.2.2.1 Total Pressure Tolerance Range for Indefinite Crew Exposure

[V2 6006] The system **shall** maintain the pressure to which the crew is exposed to between 34.5 kPa < pressure ≤ 103 kPa (5 psia < pressure ≤ 15.0 psia) for indefinite human exposure without measurable impairments to health or performance.

[Rationale: Designers and physiologists have to evaluate and trade off the various atmospheric combinations. For missions with frequent EVAs, minimizing the pressure difference between the habitat and EVA suit is preferred. Low total pressure requires a higher percentage of oxygen in the atmosphere to provide an acceptable P_IO_2. Oxygen-rich atmospheres, however, present safety hazards because of their ability to feed fires. The lowest pressure at which normoxia (P_IO_2 = 149 mmHg) is maintained at 100% O_2 is 3.8 psia, however given the need to maintain a diluent gas at 30% ([V2 6002] Inert Diluent Gas) while maintaining normoxia and CO_2 limits ([V2 6004] Nominal Vehicle/Habitat Carbon Dioxide Levels), the lowest achievable cabin pressure is 5.0 psia (see Figure 6.2-1—Atmospheric Composition). Total pressure must be considered in conjunction with O_2 and CO_2 requirements. Under certain spacesuit operations (e.g., DCS treatment, leak checks), the crewmember may be exposed to pressures above or below this range for a limited period of time.]

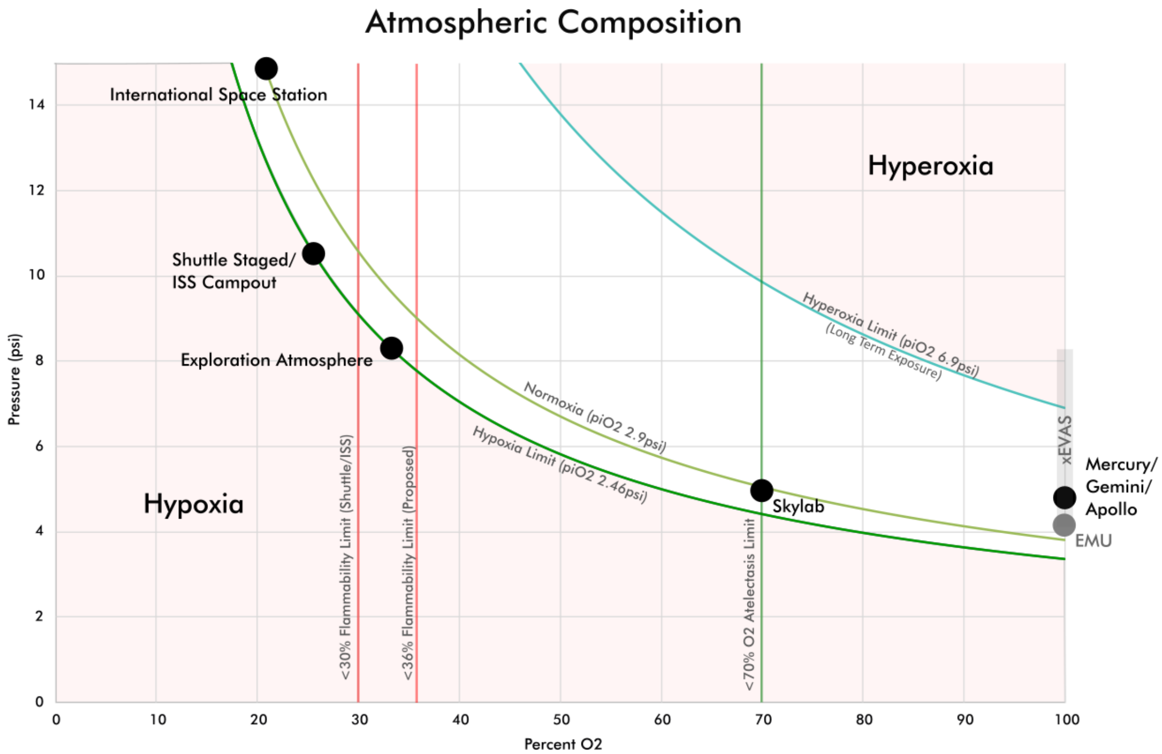


Figure 6.2-1—Atmospheric Composition

6.2.2.2 Rate of Pressure Change

[V2 6007] For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure **shall not** exceed 13.5 psi/min.

[Rationale: This rate of pressure change is used across numerous environments and provides a good boundary for human tolerance. This rate of change helps decrease risk of injury to crewmembers' ears and lungs during depressurization and repressurization but does not replace the [V2 6150] Barotrauma Prevention requirement. Microgravity may have affected head and sinus congestion and is therefore much more conservative than the 30 psi/min (1550 mmHg/min) (75 ft/min) descent rate limit allowed by the U.S. Navy Diving Manual. This rate of change limit is consistent with the U.S. Navy Diving Manual 13.5 psi/min (700 mmHg/min) (30 ft/min) ascent rate allowance, which is used primarily for DCS prevention, not barotrauma prevention. For transient pressure changes ≤ 1.0 psi, the rate of change of total internal vehicle pressure can exceed 13.5 psi/min.]

6.2.2.3 Barotrauma Prevention

[V2 6150] During a commanded pressure change, the system **shall** pause within 1 psi of the pause command being issued by the unsuited or suited crewmember, with ability to increase or decrease pressure as needed after the pause.

[Rationale: During all intentional pressure changes, crewmembers may need to pause the pressure change within the system allowing additional time to adjust to the change in pressure and to avoid barotrauma. If the pause does not alleviate discomfort, the crewmember needs to be able to reverse the direction of the pressure change. This could be necessary if a crewmember is unable to equalize pressure in their ears and sinuses.]

6.2.2.4 Decompression Sickness (DCS) Risk Identification

[V2 6008] Each program **shall** define mission unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence:

a. DCS ≤ 15% (includes Type I or isolated cutis marmorata).

b. Grade IV venous gas emboli (VGE) ≤ 20%.

c. Prevent Type II DCS.

[Rationale: DCS risk limits have been defined to develop coordinated requirements for the habitat (e.g., vehicle, EVA suit) including total pressure, ppO_2 and prebreathe before vehicle or suit depressurization, which are all variables in DCS risk. These risk limits are designed to protect crew health from severe DCS that could affect long term health: historically, <15% DCS I incidence correlates with rare DCS II (serious/neurologic/life threatening DCS) and also is associated with a high likelihood of resolution with repressurization. Specific programs/missions may require a significantly lower risk of DCS to ensure mission goals, and thus may implement a lower risk of DCS. This level of risk minimizes impact to crew long term health consequences. If DCS develops, initiating treatment as soon as possible improves the likelihood of treatment success, therefore actual or suspected DCS will most often result in EVA termination. Crewmembers also have a required 24-hr exclusion from reduced pressure activities post successful DCS treatment per JPR 1800.3E Decompression Sickness, Sections 3.1-3.3. Therefore, lower levels of risk may be necessary to minimize EVA interruption and ensure mission success. This may involve longer prebreathe times, delayed EVA mission operations or decreasing decompression stress through minimizing the change in pressure from the vehicle to the EVA suit.]

6.2.2.5 Decompression Sickness Treatment Capability

[V2 6009] The system **shall** provide DCS treatment capability.

[Rationale: DCS is a potential hazard of spaceflight and EVA because of changes in the operational pressure environment. Rapid and appropriate intervention is required to optimize the outcome for the affected crewmember. If treatment for DCS is instituted quickly, the outcome of therapy has a higher probability of success and will likely require less magnitude and duration of hyperbaric O_2 therapy.

It is important, therefore, to have the crewmember back to their initial saturation pressure as soon as possible, which may resolve DCS symptoms. Initial saturation pressure is defined as the highest pressure to which the crewmember has been exposed during the 36 hours before beginning the EVA. If not addressed quickly, higher pressures may be required to address DCS symptoms. The U.S. Navy Treatment, Table 6, Oxygen Treatment of Type II Decompression Sickness (treatment in a hyperbaric treatment facility) found in the U.S Navy Diving Manual, is the terrestrial standard for treating most forms of DCS; however, the terrestrial standard may not be achievable, or required, because the resources required to support it would be prohibitive, and the expected outcomes from sub-terrestrial standard therapy are likely to be adequate for altitude-induced DCS symptoms.]

6.2.3 Temperature and Humidity for Crew Health and Performance

6.2.3.1 Crew Health Environmental Limits

[V2 6012] The system **shall** maintain levels of cabin humidity and temperature within the boundaries of the Operating Limits as shown in Figure 6.2-2—Crew Health Environmental Limits, to protect for crew health during pressurized operations when crew occupies the cabin, excluding suited operations, ascent, entry, landing, and post landing.

[Rationale: The intent of the Crew Health Environmental Limits is to provide the range of cabin humidity and temperature that protects crew health. Figure 6.2-2 is based on ASHRAE 55 and anchored at 18°C and 75% humidity on the upper left corner and 27 °C and 25% humidity on the lower right corner. Operations outside of these boundaries may cause crewmembers to experience health impacts (dry, stuffy and/or irritated mucous membranes), skin rashes (due to microbial growth at high humidity levels) thermal discomfort (overheating depending on tasks), and/or decreased performance. From an engineering perspective, average humidity is to be maintained above this lower limit (25%) to ensure that the environment is not too dry to prevent static electricity buildup within the cabin, which could pose an electrical hazard to crew and a possible ignition hazard. Refer to [V2 6013] Crew Performance Environmental Zone for the range that protects for both health and performance. This requirement does not apply to EVA suits. Corresponding EVA suit requirements addressing temperature, humidity, pressure, and other elements that affect comfort in a spacesuit are defined in section 11 of this NASA Technical Standard.]

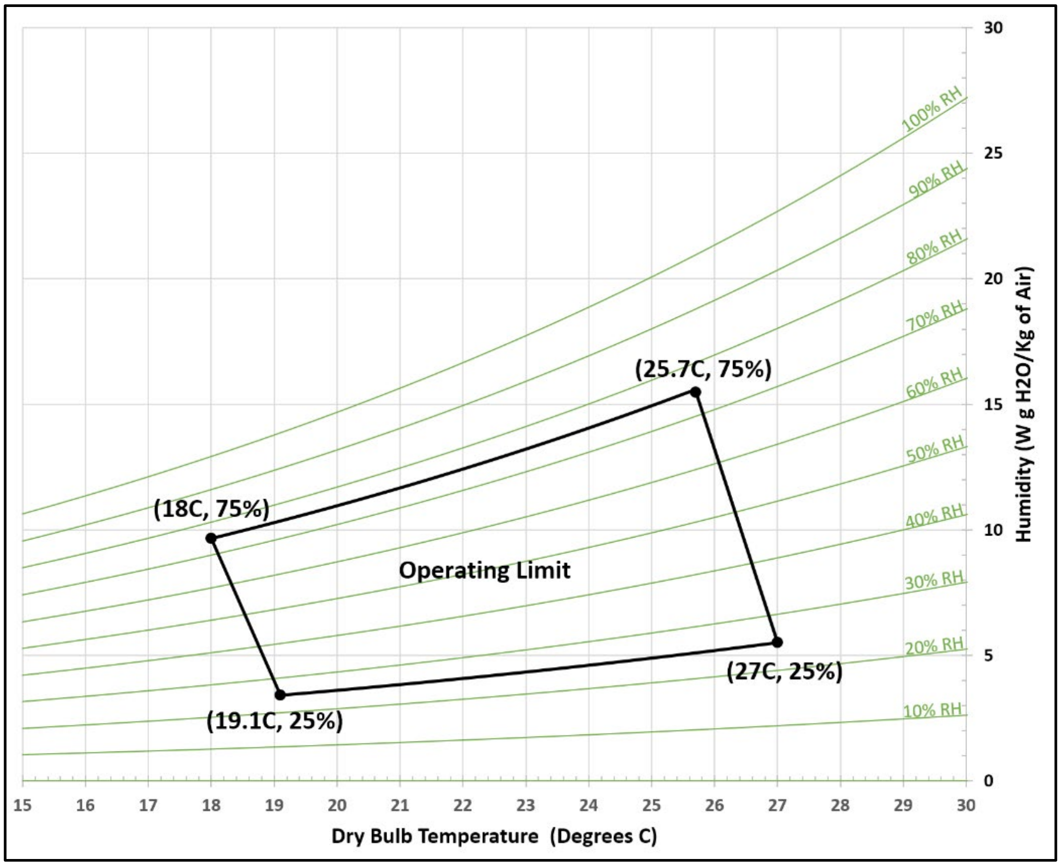


Figure 6.2-2—Crew Health Environmental Limits

6.2.3.2 Crew Performance Environmental Zone

[V2 6013] The system **shall** be capable of reaching atmospheric humidity and temperatures of nominally occupied habitable volumes within the zone provided in Figure 6.2-3—Crew Performance Environmental Zone, during all nominal operations, excluding suited operations, ascent, entry, landing, and post landing.

[Rationale: This temperature zone is defined as the operating zone of environmental conditions in which humans can achieve thermal comfort and not have their performance of routine activities affected by thermal stress. Operating outside of this zone will cause performance decrements and impact productivity. Due to individual variability among crewmembers and the likelihood of different crewmembers performing different tasks at different metabolic rates, it is necessary to have the capability to change temperature set points, adjust localized air flow, and/or have various clothing options available to achieve thermal comfort for all crew. Studies of office working environments and OSHA recommendations generally find these atmospheric parameters (20°C -25°C and 30-60% humidity) to support human comfort and performance (T.M. Ikaheimo, 2014; Seppanen, Fisk, & Lei, 2006; OSHA Policy on Indoor Air Quality: Office Temperature/Humidity and Environmental Tobacco Smoke, 2003).]

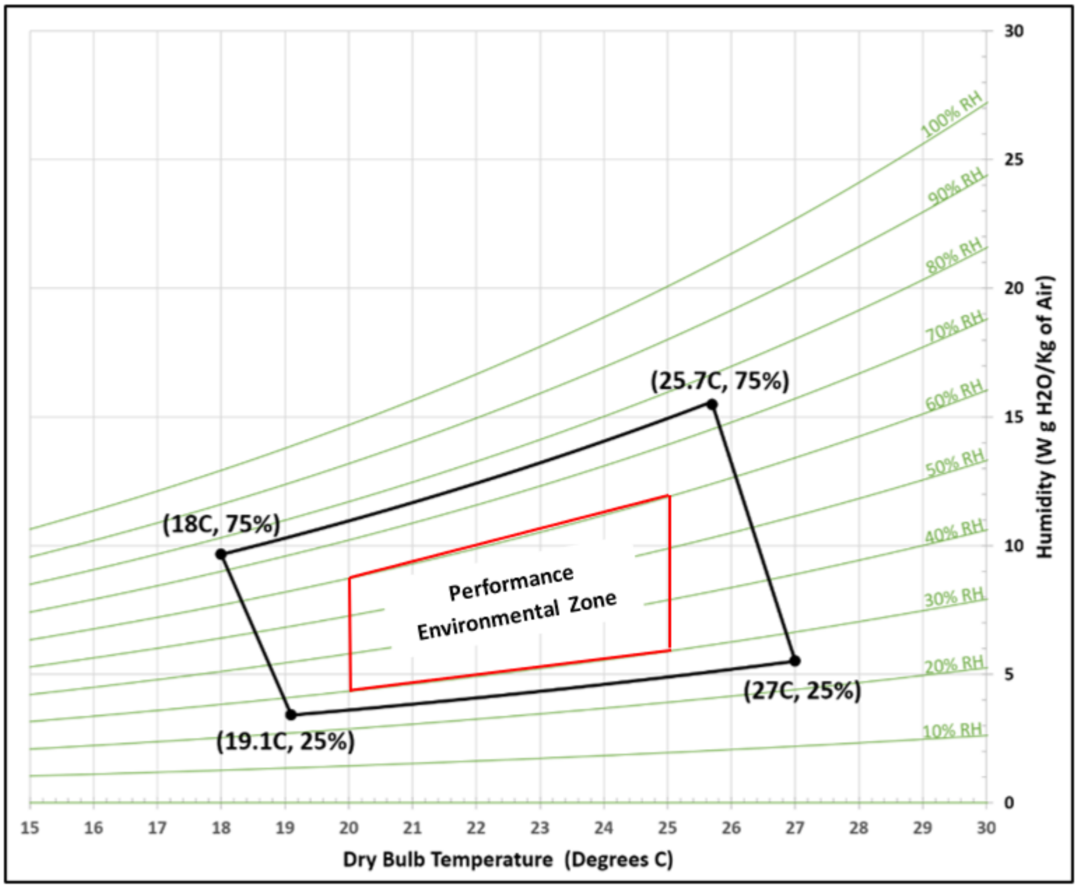


Figure 6.2-3—Crew Performance Environmental Zone

6.2.3.3 Crewmember Heat Storage

[V2 6014] The system **shall** prevent the energy stored by each crewmember from exceeding the cognitive deficit onset (CDO) limits defined by the range 4.7 kJ/kg (2.0 Btu/lb) > ΔQ stored > -4.1 kJ/kg (-1.8 Btu/lb) during pre-launch operations, ascent, entry, descent, landing, postlanding, contingency, and suited operations longer than 12 hours, where ΔQ stored is calculated using a validated and NASA-approved thermoregulatory model, such as 41-Node Man (JSC-33124, 41-Node Transient Metabolic Man Computer Program Documentation – A thermal regulatory model of the human body with environmental suit applications) or the Wissler model.

[Rationale: The intent of this requirement is to protect the crewmember from heat-related illness. Heat stored by crewmembers during launch, landing, and off-nominal suited operations may also need to be addressed as part of total system design and human accommodation. These thermal limits are intended to cover brief temperature excursions related to contingency situations, including excessively high metabolic rates, or operational exposure to excessive ambient heat loads, including suited operations.]

6.2.3.4 Temperature Selectability

[V2 6151] The system **shall** provide selectable set points for internal atmosphere temperature in step sizes no greater than 0.5°C increments with a setpoint error of +/- 1.5°C in the habitable volume.

[Rationale: The intent of this requirement is to allow the crew to adjust the temperature to accommodate crew performance and provide some adjustment for crew preference. It is expected that the system can be set to temperatures in the environmental operating range (per [V2 6012] Crew Health Environmental Limits) and the system will accommodate those temperatures if the capability exists.]

6.2.3.5 Temperature Adjustability

[V2 6152] The system **shall** be capable of adjusting temperature in the habitable volume by at least 1°C/hr.

[Rationale: The cabin temperature needs to be capable of being adjusted in a timely manner (1° Celsius per hour) in order to accommodate real-time crew activities, performance, and crew preference.]

6.2.3.6 Post Landing Relative Humidity (RH)

[V2 6011] For nominal post landing operations, the system **shall** limit RH to the levels in Table 6.2-2—Average Relative Humidity Exposure Limits for Post Landing Operations.

[Rationale: Average humidity is to be maintained above the lower limits stated to ensure that the environment is not too dry for the nominal functioning of mucous membranes. During low humidity exposures, additional water is to be provided to the crew to prevent dehydration. Humidity is to be maintained below the upper limits for crew comfort to allow for effective evaporation and to limit the formation of condensation. In unsuited scenarios, high RH may interfere with the nominal evaporation process that enables perspiration to cool the body. Thus, high RH in warm environments can pose an additional hazard for core body temperature excess.]

Table 6.2-2—Average Relative Humidity Exposure Limits for Post Landing Operations

Average RH	Time Allowed
25% < RH ≤ 75% (nominal range[1])	Indefinite[2]
75% < RH ≤ 85%	24 hr[3]
85% < RH ≤ 95%	12 hr[3]
95% < RH	8 hr[3]

1. Nominal humidity range is included for completeness.
2. Assumes temperature is within nominal range in accordance with requirement [V2 6012] Crew Health Environmental Limits in this NASA Technical Standard.
3. Only after doffing a suit post landing; duration may be shorter if temperature is outside nominal range (specified in requirement [V2 6012] Crew Health Environmental Limits in this NASA Technical Standard).

6.2.4 Atmospheric Control

6.2.4.1 Atmospheric Control

[V2 6017] The system **shall** allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO_2.

[Rationale: The ability to control atmospheric conditions is important for crew comfort, e.g., temperature and humidity, and for mission tasks, e.g., ppO_2 and total pressure for expected cabin depressurization, to ensure efficient and effective performance. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11033] Suited Thermal Control, in this NASA Technical Standard. The ability to adjust atmospheric parameters remotely is important for cases in which a crewed vehicle is to dock with an uncrewed vehicle whose atmosphere is to be habitable before ingress. This may be done from other spacecrafts located in microgravity, extraterrestrial body surfaces, or Earth- or lunar-based control centers.]

6.2.4.2 Environmental Control During Exercise

[V2 7041] The system environmental control **shall** accommodate the increased O_2 consumption and additional output of heat, CO_2, perspiration droplets, odor, and particulates generated by the crew in an exercise area.

[Rationale: The ppO_2 in the exercise area(s) is to be maintained at normal levels; otherwise, the required physiological capabilities of crewmembers may be impaired. This requirement also addresses any particulate that may be generated by the exercise activity, e.g., skin, hair, or lint from clothing or other materials.]

6.2.5 Atmospheric Data Availability

6.2.5.1 Atmospheric Data Recording

[V2 6020] For each isolatable, habitable compartment, the system **shall** automatically record pressure, humidity, temperature, ppO_2, and $ppCO_2$ data continuously.

[Rationale: Access to atmospheric data is needed for each habitable compartment (that can be isolated with a pressure hatch) to which the crew has access, as each of these parameters is critical to crew health and comfort. Additionally, the ability to view past recorded data helps to prevent environmental conditions that could harm the crew or vehicle and can aid in the effort to troubleshoot problems. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11034] Suited Atmospheric Data Recording, in this NASA Technical Standard.]

6.2.5.2 Atmospheric Data Displaying

[V2 6021] The system **shall** display real-time values for pressure, humidity, temperature, ppO_2, and $ppCO_2$ data to the crew locally and remotely.

[Rationale: These atmospheric parameters are critical to human health and comfort, and access to this atmospheric data needs to be provided to the crew. The crew needs to view the environmental status in real time to help prevent environmental conditions that could harm them or the vehicle. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11035] Suited Atmospheric Data Displaying in this NASA Technical Standard.]

6.2.6 Atmospheric Monitoring and Alerting

6.2.6.1 Atmospheric Monitoring and Alerting Parameters

[V2 6022] The system **shall** alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO_2, and $ppCO_2$ are outside safe limits.

[Rationale: Systems are to be capable of alerting the crew when atmospheric parameters are outside set limits so the crew can take appropriate actions to maintain health and safety. See section 10.5.1 Audio Systems, in this NASA Technical Standard for additional information. This requirement does not apply to spacesuits. The corresponding spacesuit requirement is defined in requirement [V2 11036] Suited Atmospheric Monitoring and Alerting, in this NASA Technical Standard.]

6.2.6.2 Trace Constituent Monitoring and Alerting

[V2 6023] The system **shall** monitor trace volatile organic compounds (VOCs) in the cabin atmosphere and alert the crew locally and remotely when they are approaching defined limits.

[Rationale: Monitoring and alerting are required to identify when hazardous contaminants are detected and to alert the crew so they can take appropriate actions to maintain health and safety. Trace contaminant monitoring is important for identifying a wide range of contaminants that may impact human health and safety, including toxic substances that cannot be predicted now or substances that are not normally thought of as part of the atmosphere. Accepted limits may be based on JSC-20584, Spacecraft Maximum Allowable Concentrations (SMACs), or on agreements from international partners. There may be specific mission scenarios (e.g., short-duration missions and alternate controls) where trace contaminant monitoring may not be required.]

6.2.6.3 Combustion Monitoring and Alerting

[V2 6024] The system **shall** monitor in real-time the toxic atmospheric components listed in Table 6.2-3—Recommended Combustion Product (CP) Monitoring Ranges, that would result from pre-combustion and combustion events in the ranges and with the accuracy and resolution specified in the table and alert the crew locally and remotely in sufficient time for them to take appropriate action.

[Rationale: Monitoring of toxic by-products of combustion is generally used for operational decisions and response. Because of the extreme danger of combustion in a spacecraft, combustion product monitors are to be readily accessible and provide quick, stable, and accurate readings. Monitoring and alerting are required to identify when toxic combustion products are present and to notify the crew to take appropriate actions to maintain health and safety.]

Table 6.2-3—Recommended Combustion Product (CP) Monitoring Ranges

<table>
<tr><th colspan="2">CP Target Required</th><th>Range[a]</th><th>Accuracy[b]</th><th>Resolution</th></tr>
<tr><td colspan="2">CO</td><td>5-1000 ppm</td><td>±10%</td><td>1 ppm</td></tr>
<tr><td colspan="2">HCN</td><td>2-50 ppm</td><td>±25%</td><td>1 ppm</td></tr>
<tr><td rowspan="4">Acid Gases (Hydrogen Halides)</td><td>HCl</td><td>2-50 ppm</td><td>±25%</td><td>1 ppm</td></tr>
<tr><td>HF</td><td>2-50 ppm</td><td>±25%</td><td>1 ppm</td></tr>
<tr><td colspan="4">OR</td></tr>
<tr><td>HX[c]</td><td>2-50 ppm</td><td>±25%</td><td>1 ppm</td></tr>
<tr><td colspan="5">[a] ppm is parts-per-million by volume at 1 atm
[b] accuracy across full listed range
[c] HX = the total concentration of halide acid gases, i.e., [HCl] + [HF] + [HBr]
Source: V.E. Ryder (2016). Volatile Combustion Product Monitoring in Spacecraft, TOX-VER-2016-03</td></tr>
</table>

6.2.6.4 Contamination Monitoring and Alerting

[V2 6025] The system **shall** monitor and display atmospheric compound levels that result from contamination events, e.g., toxic release, systems leaks, or externally originated, before, during, and after an event and alert the crew locally and remotely in sufficient time for them to take appropriate action.

[Rationale: Alerting the crew when contaminants are present is necessary for them to take appropriate action to maintain health and safety. In addition, monitoring after the event is important to verify that levels are safe for human exposure. Monitoring is required to identify when components are detected so that alerting can occur. Potential contaminants, e.g., hydrazine, monomethylhydrazine (MMH), unsymmetrical dimethylhydrazine (UDMH), nitrogen tetroxide/nitrogen dioxide and ammonia, need to be monitored after EVA.]

6.2.6.5 Celestial Dust Monitoring and Alerting

[V2 6153] The vehicle **shall** monitor celestial dust and alert the crew locally and remotely when they are approaching defined limits.

[Rationale: Celestial dust includes, but is not limited to, lunar, Martian and other extraterrestrial bodies. In-flight monitoring of habitable environments is required to characterize concentrations of celestial dust which enables any necessary crew action to

maintain health and safety, tracking of average exposure, while also informing necessary treatment options after the mission, and providing a record of crew exposures. Lunar dust monitoring frequency and particle size fraction is dependent on mission characteristics and whether crew health concerns are based on chronic or acute exposure considerations as noted in [V2 6053] Lunar Dust Contamination. There may be other specific mission scenarios (e.g., surface launch vehicle docking to orbital vehicle) where dust monitoring may be required.]

6.2.7 Atmospheric Ventilation

6.2.7.1 Nominal Vehicle/Habitat Atmospheric Ventilation

[V2 6107] The system **shall** maintain a ventilation rate within the internal atmosphere that is sufficient to provide circulation that prevents CO_2 and thermal pockets from forming, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.

[Rationale: Crew and equipment give off heat, moisture, and CO_2 that will lead to parameters outside the bounds of environmental requirements if adequate ventilation is not provided. Maintaining proper ventilation within the internal atmosphere is necessary to ensure that stagnant pockets do not form, and the temperature, humidity, and atmospheric constituents are maintained within their appropriate ranges. The two-thirds value for atmosphere velocities in the requirement has historically proven to be a reasonable balance between design constraints such as power, acoustics, and safety. The effective atmosphere velocity range of 4.57-36.58 m/min (15-120 ft/min) pertains to the time averaged velocity magnitudes in the crew occupied space using averages over time periods sufficient to achieve stability. This range is considered sufficient to provide circulation that prevents CO_2 and thermal pockets from forming. Cabin ventilation is not required during suited operation since the suit will provide necessary air circulation. Fire or any toxic release into the atmosphere are examples of periods during which the mentioned ventilation rates are not in the best interest of air quality and crew health. In those cases, the ventilation system may need to be shut down to protect the safety of the crew.]

6.2.7.2 Off-Nominal Vehicle/Habitat Atmospheric Ventilation

[V2 6108] The system **shall** control for ppO_2, $ppCO_2$, and relative humidity during off-nominal operations, for example during temporary maintenance activities in areas not in the normal habitable volume.

[Rationale: The crew may be required to perform maintenance behind a panel in an area that is not part of the normal habitable volume, and which therefore does not have ventilation. Maintaining proper ventilation within the internal atmosphere is necessary to ensure that stagnant pockets do not form, and the temperature, humidity, and atmospheric constituents are maintained within their appropriate ranges. See [V2 6003] O_2 Partial Pressure Range for Crew Exposure, [V2 6004] Nominal Vehicle/Habitat Carbon Dioxide Levels, and [V2 6012] Crew Health Environmental Limits, in this NASA Technical Standard. Examples of historical ventilation techniques include equipment such as flexible (reconfigurable) ducting, portable fans, or diverters.]

6.2.8 Atmospheric Contamination

Note: For contamination, units of measure are expressed in metric units only in the sections that follow.

6.2.8.1 Atmosphere Contamination Limit

[V2 6050] The system **shall** limit gaseous pollutant accumulation in the habitable atmosphere below individual chemical concentration limits specified in JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants (SMACs).

[Rationale: Exposure limits for expected airborne spacecraft contaminants are established to protect crewmembers from illness and injury. The SMACs provide guidance for short-term (1 and 24 hours), medium-term (7 and 30 days), and long-term (180 days and 1,000 days) exposure of these constituents. The SMACs take into account several unique factors of human spaceflight missions, including the stress on human physiology, the uniform good health of astronauts, and the absence of pregnant or very young individuals. Short-term SMACs are intended for off-nominal events and are not to be used for system design or evaluation of routine exposures. Considerations are to be taken for scenarios where there is a period of dormancy or uncrewed operations.]

6.2.8.2 Particulate Matter

[V2 6052] The system **shall** limit the habitable atmosphere particulate matter concentration for total dust to <3 mg/m^3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 µm (micrometer) in aerodynamic diameter to <1 mg/m^3 with a crew generation rate of 0.006 mg/person-minute.

[Rationale: These values were derived by applying a factor of five to the OSHA limits for nuisance dusts, which is the best analog for the ordinary dust present in spacecraft. They do not apply to reactive dust, e.g., lithium hydroxide (LiOH) or extraterrestrial dust. The factor of five is applied to adjust from intermittent occupational exposure to continuous spaceflight exposure. The basis for the particulate matter generation rates is documented in ICES-2019-58, The Impacts of Cabin Atmosphere Quality Standards and Control Loads on Atmosphere Revitalization Process Design. The generation rate for the respirable fraction of the total dust was calculated by adding the generation rate for particles <1 µm in diameter and one-half the generation rate for particles with diameters between 1 µm and 5 µm.]

6.2.8.3 Lunar Dust Contamination

[V2 6053] The system **shall** limit the levels of lunar dust particles less than 10 µm in size in the habitable atmosphere below a time-weighted average of 0.3 mg/m^3 during intermittent daily exposure periods that may persist up to 6 months in duration.

[Rationale: This limit was based on detailed peer-reviewed studies completed by the Lunar Atmosphere Dust Toxicity Assessment Group (LADTAG) and is specific to the conditions relevant to the lunar surface, i.e., this requirement would not necessarily be applicable to other missions. The requirement assumes that the exposure period is episodic and is limited to the time before ECLSS can remove the particles from the internal atmosphere (assumed as eight hours post introduction). Although the requirement is being conservatively applied to all inhalable particles (all particles ≤10 µm), it is most applicable to dusts in the respirable range (≤2.5 µm) that can deposit more deeply into the lungs. Studies show that the particle size of lunar dust generally falls within a range of 0.02-5 µm. The ability to meet this requirement will depend upon factors such as the level of lunar dust introduction and ECLSS removal rates. The monitoring of dust is captured in [V2 6153] Celestial Dust Monitoring and Alerting.]

6.2.8.4 Microbial Air Contamination

[V2 6059] The system **shall** provide air in the habitable atmosphere that is microbiologically safe for human health and performance.

[Rationale: Microbiologically safe air is essential to prevent infection, allergic response, and mitigate risk to crew health and performance. Assessing microbiological safety of air relies primarily on the enumeration and identification of viable, medically significant microorganisms (bacteria and fungi) that are known to cause disease. Historically, atmospheric microbial concentrations in spacecraft habitable atmosphere have been controlled by maintaining a continuous flow of air through High Efficiency Particulate Air (HEPA) filters that remove at least 99.97% of airborne particles 0.3 µm in diameter, or larger. Medical significance of microorganisms and allowable levels of microorganisms are set based on guidance from the JSC Microbiology Laboratory. Program level requirements for atmospheric quality include considerations for factors such as vehicle architecture and mission duration. Considerations are to be taken for scenarios where there is a period of dormancy or uncrewed operations.]

6.3 Water

The challenges of providing quality water vary for different system designs and diverse water sources, e.g., recycled humidity condensate and ground-supplied water. In the design process, early identification of potential water quality impacts enables mitigation by design. Water quality monitoring through the use of in-flight and preflight analysis techniques are essential tools for use in verifying water quality, evaluating trends, and documenting potential exposures.

6.3.1 Water Quality and Monitoring

6.3.1.1 Potable Water Quality

[V2 6026] At the point of crew consumption or contact, the system **shall** provide aesthetically acceptable potable water that is chemically and microbiologically safe for human use, including drinking, food rehydration, personal hygiene, and medical needs.

[Rationale: Point of crew consumption or contact refers to the location from which potable water is dispensed for use in drinks, food rehydration, personal hygiene, medical needs, and any potential in-flight maintenance sites. Safe water pollutant levels have been established for certain prioritized compounds specifically for human-rated space vehicles by the JSC Toxicology and Environmental Chemistry Laboratory in cooperation with a subcommittee of the National Research Council Committee on Toxicology; however, the current list in JSC-63414, Spacecraft Water Exposure Guidelines (SWEGs), is not all inclusive, and other compounds may be of concern. For these other compounds, the United States Environmental Protection Agency maximum contaminant levels can be utilized as conservative screening limits. For additional guidance, reference chapter 6, Natural and Induced Environments, in the Human Integration Design Handbook (HIDH). To determine which contaminants are present, a complete chemical characterization of potential water sources is to be performed. Evaluation of aesthetic properties is important to ensure that the potable water does not have an adverse odor or taste such that it would cause crewmembers to diminish consumption and increase the risk of underhydration or dehydration of the crewmember. Aesthetic acceptability can either be assessed qualitatively by an evaluation panel or indirectly through compliance with the applicable water quality requirements.

Special considerations need to be taken with treatment chemicals and residual biocides. For example, at effective biocidal levels iodine can alter the aesthetics of the water as well as cause iodine-related illness; refer to Section 6.3 of the HIDH, NASA/SP-2010-3407. Allowable concentrations for other treatment chemicals and biocides can be found in JSC-63414 and United States Environmental Protection Agency guidelines.

Microbially safe water is essential to prevent infection and mitigate risk to crew health and performance. Microbiological assessment of water safety relies primarily on the identification of viable, medically significant microorganisms (bacteria, fungi, and parasitic protozoa) that are known to cause disease. Monitoring targets have included specific categories of microorganisms (e.g., coliform bacteria) that indicate that the water may have been contaminated or not adequately treated. Microbial enumeration of potable water has also been used historically as an indicator of overall system performance. Previous spaceflight missions have used these monitoring approaches in combination with mitigation strategies to confirm the safety of potable water. Medical significance of microorganisms and allowable levels of microorganisms are set based on guidance from the JSC Microbiology Laboratory. Program level requirements for water quality include considerations for factors such as water source, vehicle architecture, and mission duration.]

6.3.1.2 Water Contamination Control

[V2 6051] The system **shall** prevent potable and hygiene water supply contamination from microbial, atmospheric (including dust), chemical, and non-potable water sources to ensure that potable and hygiene water are provided.

[Rationale: While ensuring the delivery of potable water to crew on orbit is important, contamination from sources within the delivery system or from the environment is also possible.]

6.3.1.3 Water Quality Monitoring and Alerting

[V2 6046] The system **shall** provide the capability to monitor water quality and notify the crew locally and remotely when parameters are approaching defined limits.

[Rationale: On-orbit water quality is critical to the health of the crew as required in [V2 6026] Potable Water Quality. Rigorous ground processing with preflight water sampling and contamination assessment prevents in-flight water quality problems and thus minimizes the need for in-flight contamination monitoring and remediation of any water quality parameters that are out of specification. In-flight sampling capability supports real-time contaminant monitoring and remediation of stored or regenerated water systems as needed for long-duration missions. Ground-based quality analyses of in-flight and post landing samples provide a record of crew exposures and are used to determine follow-on ground processing steps.]

6.3.2 Water Quantity

[V2 6109] The system **shall** provide a minimum water quantity as specified in Table 6.3-1—Water Quantities and Temperatures, for the expected needs of each mission, which are considered mutually independent.

[Rationale: To maintain crewmember hydration status and allow crewmembers to perform duties nominally, adequate water intake is needed, which is a culmination of drinking water, dietary intake from food and drinks, as well as fluid loading and recovery needs. Proper hydration contributes to adequate urine output to clear metabolic wastes and to account for perspiratory and other insensible losses. Dehydration of the crewmember will have consequences ranging from poor communication and crewmember performance caused by dry mucous membranes, nosebleeds, headache, malaise, and fitful sleep to urinary tract infection or urinary calculi if the under-hydration state is continued. Dehydration also cancels many of the thermal benefits of heat acclimatization and aerobic fitness. Potable water is also necessary during suited operations to prevent dehydration related to perspiration and insensible water loss, as well as to improve comfort.

For fluid loading, 1.5 L of water per crewmember is based on the Space Shuttle and the Commercial Crew Program (CCP) prescriptions for reentry fluid loading. Table 6.3-1 calls out a minimum of 1 L (33.8 fl oz) of water per crewmember, and an additional 500 mL (16.9 fl oz) will be available per crewmember from their unused daily water allocation. Vehicles that may wave off prior to reentry need to protect for two fluid loadings per crewmember. Fluid loading is based on crewmember weight and requires the use of salt tablets in addition to water unless an alternative solution is used. Without fluid loading, the crew is more likely to experience orthostatic intolerance (passing out when standing) during and after deorbit.

Of note, the water required during the post landing phase, for up to about 36 hours, is to ensure crewmembers are properly hydrated. Less water may be needed for hydration following a launch abort, since crewmembers will not have undergone spaceflight fluid loss. Additionally, for *missions longer than a few days, hot and cold food and beverages provide an important psychological benefit. The amount of hot and cold water to be provided depends on the number of crew, mission length, and types of food and beverage available. To ensure the crew have adequate hydration, the Potable Water for Hydration minimum amount per day is available for drinking, and for rehydrating foods/drinks. This value does not change with removal of rehydratable foods or addition of thermostabilized food as the minimum amount is based on the physiological needs and not how it is consumed.*

Water is also needed for personal hygiene, which will depend on the mission length, number of crewmembers, and design of the hygiene system. Clean water is necessary for maintaining skin, hair, and dental health of the crew. Water may not be required for some hygiene activities where alternatives, e.g., rinseless shampoo, pre-wetted towels, are provided. Water for medical contingency use is required for many situations, including wound irrigation during the various activities of a mission, which is based on experience and data from Shuttle, ISS, and Apollo programs. The amount of contingency water will be determined on the expected events to occur and frequency of events. Eye wash capability for particulate events is expected, especially for lunar and planetary missions, as there is an increased risk of exposure to dust and regolith on the lunar or other planetary surfaces. Some medical situations require large quantities of water, for example, LiOH or other toxic substances in the eye or skin, or in a wound. However, these events are off-nominal and occur at lower frequency during the mission than particulate events and may be considered contingencies. The quantity of water to be provided depends on the number of crewmembers, duration of mission, and expected contingency events and should ensure that medical treatment can be provided.

Additional considerations for water quantities include sampling needs for routine water testing and monitoring, as well as any agricultural or hydroponic systems that would be in addition to the crew needs for hydration. All quantities are considered mutually independent. Water quantities provided are not limited to only what is replenished with the arrival of cargo or crew vehicles and can be obtained by other means, including that of recycling.]

6.3.3 Water Temperature

[V2 6110] The system **shall** provide the appropriate water temperature as specified in Table 6.3-1—Water Quantities and Temperatures, for the expected needs of each mission and task.

[Rationale: Over the course of long-duration missions, crewmembers can tire of repetitive beverages and foods. Providing hot and cold water is an important way of keeping the crewmembers interested in their meals and providing a familiar contact to normal Earth living, as well as making the food items more acceptable and palatable. During the Apollo missions, it was noted that the crew reported that there was a need for hot water while in the lander to not only provide warmth, but as comfort during the missions. To aid in the well-being and for any food/drinks consumed, a portion (600 mL) of the potable water will need to be available as hot water for immediate use. However, the minimum water needed per crewmember per day is 2.5 L (84.5 fl oz), regardless of the portions allocated as hot, cold or room temperature. Additionally,

the use of higher water temperatures allows for faster rehydration of beverages and foods, as well as aiding in the prevention of microbial growth.

Providing proper temperature of hygiene and medically used waters will support comfortable body cleansing and prevent thermal injury to the tissue, especially when performing irrigations. Terrestrially, building code for typical shower valves is to limit the outlet temperature to 120°F (48.9C), which is at the tissue damage limit. Note that the average ISS Potable Water Dispenser (PWD) hot water is 180°F (~82°C) but can vary from 150-200°F (~65-93°C). Crewmembers are trained to use a combination of Ambient and Hot to get the desired temperature for hygiene.]

Table 6.3-1—Water Quantities and Temperatures

Requirement	Quantity (quantities are mutually independent)	Temperature		
		Hot	Nominal	Cold
Potable Water for Hydration[††]	Minimum 2.5 L (84.5 fl oz) per crewmember per day *(allocation to include 600 mL per meal per crewmember to be available as Hot Water)*	between 68ºC (155ºF) and 79ºC (175ºF)**	between 18ºC (64ºF) and 27ºC (81ºF)	maximum temperature of 16ºC (60ºF)
Potable Water Quantity for Personal Hygiene	Minimum 400 mL (13.5 fl. oz.) per crewmember per day	between 29ºC (85ºF) and 46ºC (115ºF)		
Potable Water Quantity for Eye Irrigation	Minimum 500 mL (16.9 fl oz) per crewmember	between 16ºC (60ºF) and 38ºC (100ºF)		
Potable Water for Medical Use and Medical Contingency	Minimum of 5 L (169.1 fl oz) per event	between 18ºC (64ºF) and 27ºC (81ºF)		
Potable Water for EVA Operations	Minimum 240 mL (8.1 fl oz) per crewmember per EVA hour	between 68ºC (155ºF) and 79ºC (175ºF)	between 18ºC (64ºF) and 27ºC (81ºF)	maximum temperature of 16ºC (60ºF)
Potable Water for Fluid Loading for Reentry from Microgravity to Partial or Earth Gravity	Minimum of 1 L (33.8 fl oz) per crewmember*			
Potable Water for Crew Recovery During Entire Recovery Period	Minimum of 1 L (33.8 fl oz) per crewmember for every 8-hour period			
Sampling Water Quantity	Mission dependent***	N/A		
Agriculture Water Quantity	Mission dependent***	TBD		

** Vehicles that may wave-off prior to reentry are to protect for this quantity of water for fluid loading for each of two deorbit attempts.*
*** Critical for missions longer than three days.*
**** Mission dependent as sized by appropriate sampling or plant science personnel.*
†† The bulk supply of water should be accessible as nominal and/or cold, with the total of water provided for hydration is minimally 2.5L regardless of temperature.

6.3.4 Water Dispensing

6.3.4.1 Potable Water Dispensing Rate

[V2 6039] Water **shall** be dispensed at a rate that is compatible with the food system.

[Rationale: A water dispensing rate is to be defined as a rate that is compatible with the food packaging and time demands of the allotted meal schedule to ensure that the crew is able to prepare for and perform tasks, e.g., filling drink bags and/or rehydrating food in a reasonable

amount of time. The rate will depend on the design of the food system and the amount of water required, if necessary, to rehydrate beverages and food. The program will define appropriate increments in accordance with HMTA. This rate is not intended to require an additional water quantity beyond that required for nominal mission water usage. It needs to be compatible with the increments, for example a rate of 500 mL/minute (16.9 oz/minute) can ensure timely food preparation when rehydration is needed for multiple meals or drinks for all crewmembers and meals.]

6.3.4.2 Potable Water Dispensing Increments

[V2 6040] To prevent overflow, water **shall** be dispensable in specified increments that are compatible with the food preparation instructions and time demands of the allotted meal schedule.

[Rationale: Water dispensing increments are to be defined to properly hydrate food and beverages. In addition, palatability is to be included as part of the assessment when determining the proper hydration of food and beverages. On ISS today, water is dispensed at 25 mL (milliliter) increments. All food portions are sized to be compatible with this increment (i.e., 25 mL to 250 mL). The increment was different in previous missions, as low as 15 mL. The program will define appropriate increments in accordance with HMTA.]

6.4 Environmental Hazards

The system interior atmosphere, water, or surfaces can become contaminated from multiple in-flight sources during operations, including material offgassing, payloads, other vehicles, crew, and planetary environments. Accordingly, only those materials or substances that, if offgassed or released into the habitable volume, do not or will not form hazardous substances and would not threaten human health, are to be used within the spacecraft.

6.4.1 Toxic Chemicals

6.4.1.1 Toxic Hazard Level Three

[V2 6047] The system **shall** use only chemicals that are Toxic Hazard Level Three or below, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, in the habitable volume of the spacecraft.

[Rationale: Potential contamination assessed as Toxic Hazard Level Four cannot be cleaned up by the crew and pose a risk of permanent injury or death. As such, only materials that either pose limited risk to crew or can be contained and disposed of by an appropriate clean-up procedure should be used in the habitable volume or in systems that may credibly be released into the habitable volume (i.e., thermal working fluids). Toxic Hazard Level ratings are assigned by JSC Toxicology based on information received per JSC-27472, Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals to be Flown on Manned Spacecraft.]

6.4.1.2 Toxic Hazard Level Four

[V2 6048] The system **shall** prevent Toxic Hazard Level Four chemicals, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, from entering the habitable volume of the spacecraft.

[Rationale: Potential contamination assessed as Toxic Hazard Level Four cannot be contained by crew and may cause appreciable effects on coordination, perception, memory, long-term serious injury (e.g., cancer), or may result in internal tissue damage. Toxic Hazard Level ratings are assigned by JSC Toxicology based on information received per JSC-27472, Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals to be Flown on Crewed Spacecraft. Utilization of THL-4 chemicals may be acceptable in the external environment provided they are not brought inside habitable environment, do not contaminate and/or damage hardware that is brought inside, and/or damage other external end items.]

6.4.1.3 Chemical Decomposition

[V2 6049] The system **shall** use only chemicals that, if released into the habitable volume, do not decompose into hazardous compounds that would threaten health during any phase of operations.

[Rationale: Only a few compounds, such as fluorinated coolants, have been shown to decompose into hazardous compounds during nominal spacecraft Atmosphere Revitalization System (ARS) operation. These compounds could present a toxic threat if the amount of the compound involved is sufficient, the ARS temperature is adequate, and the product compound is hazardous. Halon is an example of such a chemical; if it is sufficiently heated during its normal use as a fire suppressant, it breaks down into highly toxic gaseous compounds.]

6.4.2 Cross-Contamination Prevention

6.4.2.1 Biological Payloads

[V2 6060] Biological payloads, as well as the associated operational procedures and supporting personal protective equipment, **shall** meet the criteria defined by the JSC Biosafety Review Board guidelines contained in JPR-1800.5, Biosafety Review Board Operations and Requirements.

[Rationale: Biohazardous agents, which include bacteria, fungi, protozoa, viruses, cell cultures, and recombinant deoxyribonucleic acid (DNA), may be infectious and result in disease or contamination of water and food supplies or the internal environment. Payloads that contain biohazardous materials are to ensure that these materials are properly contained, handled, and discarded. JPR-1800.5 establishes requirements for the identification and assessment of biohazardous materials used in payload or ground-based experiments.]

6.4.2.2 Environment Cross-Contamination

[V2 6061] The system **shall** provide controls to prevent or minimize (as appropriate) biological cross-contamination between crew, payloads and vehicles to acceptable levels in accordance with the biosafety levels (BSL) defined in JPR-1800.5, as well between crew, payloads, vehicles and extraterrestrial planetary environments with the extent of application specific to individual planetary bodies and special locations thereon.

[Rationale: Biological contamination from crew, payloads (e.g., animals, plants, microorganisms), vehicle systems, waste, suits, spacecraft vehicle, and planetary environments can negatively affect crew health, performance of the vehicle and its systems, as well as the collection and integrity of scientific data (including the potential detection of microbial life forms). Additionally, biological contamination may risk planetary protection of the Earth via back-contamination upon return. Vehicle design and capability considerations related to the disposition of the crewmember remains as stated in [V1 3053] Crew Mortality Remains Disposition and [V1 3054] In Situ Disposition of Deceased Crewmember Remains in Volume 1 of this NASA Technical Standard will need to be included. Planetary protection categories and guidance to determine the applicability and extent of planetary protection measures for extraterrestrial environments as well as for return to Earth are documented in NPD 8020.7, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft, and NID 8715.129 (or superseding documents) for the Moon and Mars. These documents are founded on, and consistent with the Committee for Space Research (COSPAR) Policy for Planetary Protection, an accepted approach for complying with the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (UN, 1967), Article IX.]

6.4.3 Availability of Environmental Hazards Information

[V2 6062] The system **shall** provide toxicological and environmental hazard information in formats accessible by the crew and ground personnel throughout the mission.

[Rationale: In case of accidental contact with hazardous materials during a mission, crew and ground personnel having access to hazard information, e.g., Safety Data Sheets (SDSs), is necessary to determine methods of cleanup and exposure treatment.]

6.4.4 Contamination Cleanup

[V2 6063] The system **shall** provide a means to remove or isolate released chemical and biological contaminants and to return the environment to a safe condition.

[Rationale: In the event of a contamination event, contaminants are to be removed, isolated, or reduced from the environment to ensure the crew's health and ability to continue the mission. In some cases, such as a spill or leak, vehicle systems may be unable to remove the contaminant; and the crewmembers will have to perform the cleanup themselves. Cleanup of a contamination includes the control and disposition of the contamination.]

6.5 Acceleration and Dynamic Loads

Exceeding acceleration limits can significantly impair human performance and cause injury, thereby threatening mission success and crew survival.

For mission durations > 30 days, the crew is considered deconditioned. For mission durations ≤ 30 days, the crew is considered non-deconditioned. Emergency conditions refer to off-nominal conditions within first 30 days of Earth launch where crew survival is prioritized (e.g., launch aborts, emergency entry). The following coordinate frame as seen in Figure 6.5-1—Common XYZ Coordinate Frame for Translational Acceleration, oriented with respect to the crewmember, is employed for these requirements:

- *X-Direction (Longitudinal, Forward/Aft)*
    - *+X: Body accelerations forward/Eyes back*
    - *-X: Body accelerations backwards/Eyes forward*
- *Y-Direction (Lateral, Side to Side)*
    - *+Y: Body accelerations left/Eyes right*
    - *-Y: Body accelerations right/Eyes left*
- *Z-Direction (Vertical, Up/Down)*
    - *+Z: Body accelerations up/Eyes down*
    - *-Z: Body accelerations down/Eyes up*

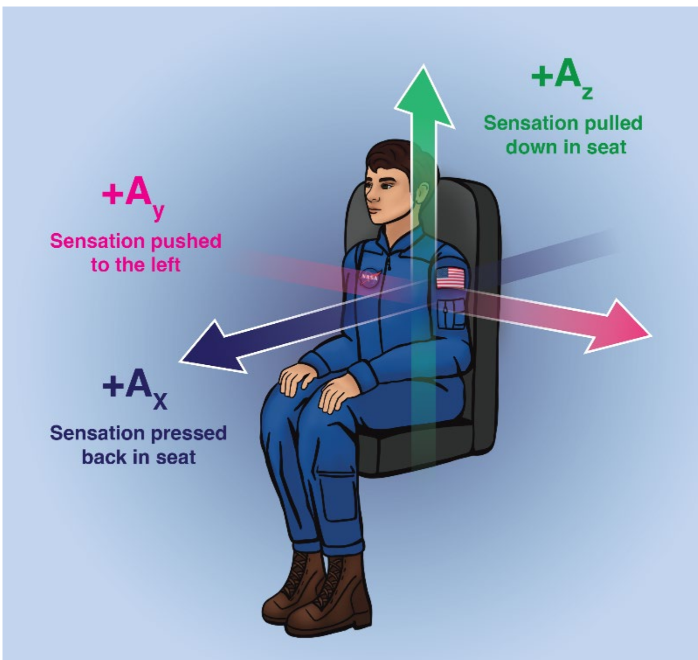


Figure 6.5-1—Common XYZ Coordinate Frame for Translational Acceleration

6.5.1 Sustained Translational Acceleration Limits

[V2 6064] The system **shall** limit the magnitude, direction, and duration of crew exposure to sustained (> 0.5 seconds) translational acceleration by staying below the limits in Figures 6.5-(2-7) and Tables 6.5-(1-6) for seated and standing postures.

[Rationale: The limits in these figures represent safe levels of sustained translational acceleration under nominal and off-nominal conditions. Exposure to acceleration above these limits could significantly affect human performance for maneuvering and interacting with a spacecraft. A separate limit is defined for deconditioned crew because crewmembers are expected to have degraded capabilities due to deconditioning from exposure to reduced gravity. For the extreme conditions of a launch abort or emergency entry, limits are higher because it may be necessary to expose the crew to accelerations more severe than those experienced nominally. Humans are never to be exposed to translational acceleration rates greater than these elevated limits, as this significantly increases the risk of incapacitation, thereby threatening crew survival. The acceleration vectors are relative to the "axis" of the upper body, particularly with a focus on a line running from the eye to the heart with the neck in a neutral posture. However, the acceleration limit charts do not account for all body types or temporary off-axis accelerations or body positions. Each axis is to be analyzed separately, and conservatism in the limits for each axis covers any cumulative effect of acceleration in multiple axes.

All limits further assume adequate restraint(s) are provided for all body postures during the period of sustained loading. Adequate restraint for the purposes of Linear Sustained Acceleration Limits are defined as devices sufficient to arrest motion between the occupant and vehicle interior by applying counterforce. Restraints must also prevent unintended contact between the crewmember and the interior of the vehicle within the linear sustained acceleration limits described herein, while facilitating continual access to and operation of vehicle displays and controls. All limits also assume the crew is wearing a counterpressure garment intended to mitigate the effects of orthostatic intolerance.

For applying the standing limits refer to NASA/TM-20205008196 Artemis Sustained Translational Acceleration Limits: Human Tolerance Evidence from Apollo to International Space Station.]

Table 6.5-1—Ax Sustained Translational Acceleration Limits (Seated)

Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	120	300	1200
	Acceleration [m/s^2]	373	86.3	73.5	49.0
Lower limit	Duration [s]	0.5	120	300	1200
	Acceleration [m/s^2]	-284	-75.5	-60.8	-42.2

Acceleration limits for non-deconditioned crew (seated)

Upper limit	Duration [s]	0.5	5	300	
	Acceleration [m/s^2]	186	157	73.5	
Lower limit	Duration [s]	0.5	5	120	400
	Acceleration [m/s^2]	-216	-147	-58.8	-39.2

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	10	30	50	90	120	150	10000
	Acceleration [m/s^2]	137	98.1	78.5	61.8	49.0	42.2	39.2	39.2
Lower limit	Duration [s]	0.5	10	30	50	90	100	10000	
	Acceleration [m/s^2]	-132	-78.5	-58.8	-46.1	-39.7	-39.2	-39.2	

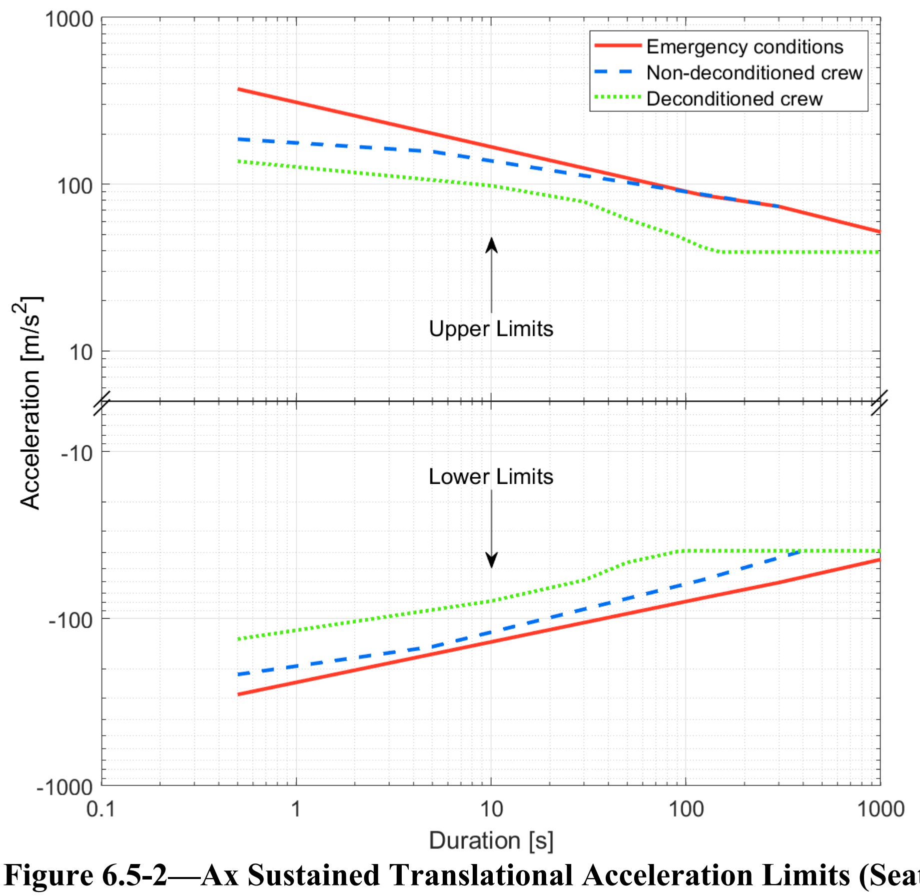


Figure 6.5-2—Ax Sustained Translational Acceleration Limits (Seated)

Table 6.5-2—Ay Sustained Translational Acceleration Limits (Seated)

Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	1000
	Acceleration [m/s^2]	49.0	19.6
Lower limit	Duration [s]	0.5	1000
	Acceleration [m/s^2]	-49.0	-19.6

Acceleration limits for non-deconditioned crew (seated)

Upper limit	Duration [s]	0.5	1000
	Acceleration [m/s^2]	29.4	19.6
Lower limit	Duration [s]	0.5	1000
	Acceleration [m/s^2]	-29.4	-19.6

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	19.6	9.81	9.81
Lower limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	-19.6	-9.81	-9.81

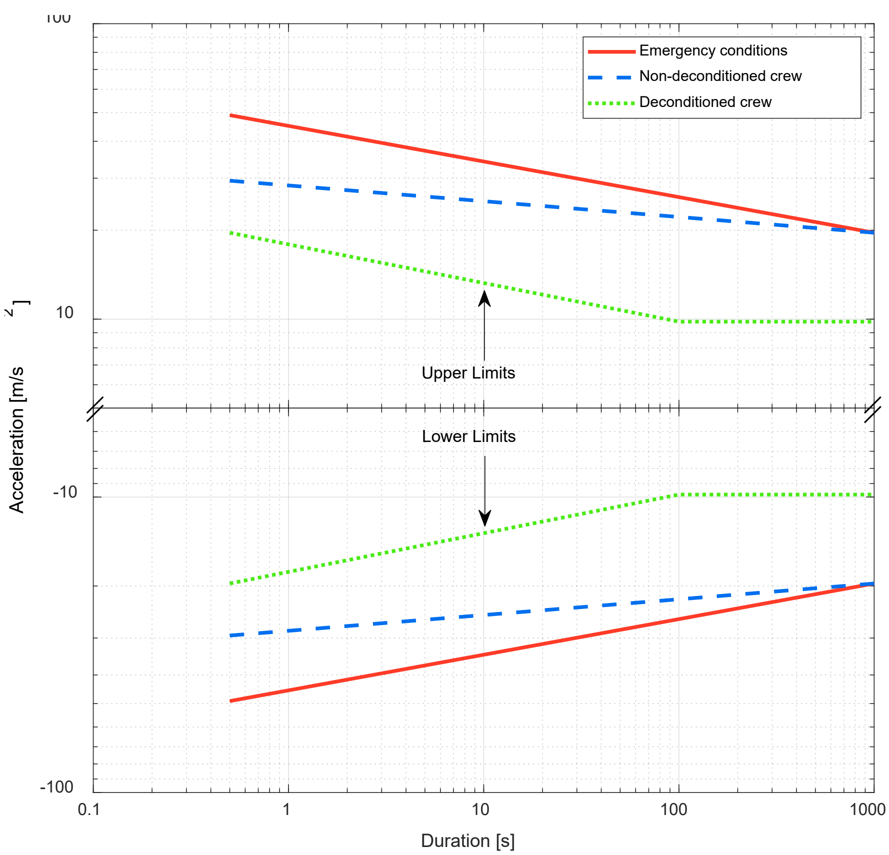


Figure 6.5-3—Ay Sustained Translational Acceleration Limits (Seated)

Table 6.5-3—Az Sustained Translational Acceleration Limits (Seated)

Acceleration limits for emergency conditions (seated)

Upper limit	Duration [s]	0.5	120	1200
	Acceleration [m/s²]	167	58.8	37.3
Lower limit	Duration [s]	0.5	120	1200
	Acceleration [m/s²]	-63.7	-22.6	-15.7

Acceleration limits for non-deconditioned crew (seated)

Upper limit	Duration [s]	0.5	5	1200	
	Acceleration [m/s²]	81.4	62.8	39.2	
Lower limit	Duration [s]	0.5	5	60	1200
	Acceleration [m/s²]	-58.8	-37.3	-21.6	-9.81

Acceleration limits for deconditioned crew (seated)

Upper limit	Duration [s]	0.5	15	30	50	80	100	120	1000
	Acceleration [m/s²]	19.6	12.3	9.81	7.85	6.67	5.88	4.90	4.90
Lower limit	Duration [s]	0.5	1000						
	Acceleration ($A_T < 9.81$ m/s²) [m/s²] *	0	0						
	Acceleration ($A_T \geq 9.81$ m/s²) [m/s²] *	1.96	1.96						

*The lower A_z acceleration limit is 0 m/s² from Entry Interface until the total Linear Reaction A_T reaches 9.81 m/s², then the limit is 2 m/s², where $A_T = \sqrt{A_x{}^2 + A_y{}^2 + A_z{}^2}$.

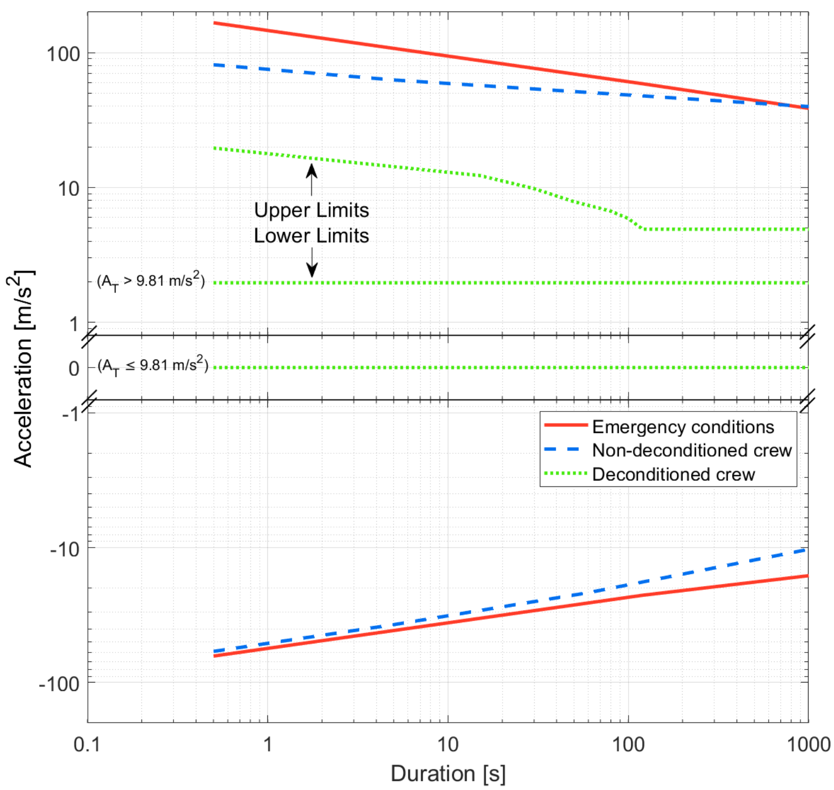


Figure 6.5-4—Az Sustained Translational Acceleration Limits (Seated)

Table 6.5-4—Ax Sustained Translational Acceleration Limits (Standing)
Acceleration limits for deconditioned crew (standing)

Upper limit	Duration [s]	0.5	10	30	50	90	120	150	10000
	Acceleration [m/s^2]	137	98.1	78.5	61.8	49.0	42.2	39.2	39.2
Lower limit	Duration [s]	0.5	10	30	50	90	100	10000	
	Acceleration [m/s^2]	-132	-78.5	-58.8	-46.1	-39.7	-39.2	-39.2	

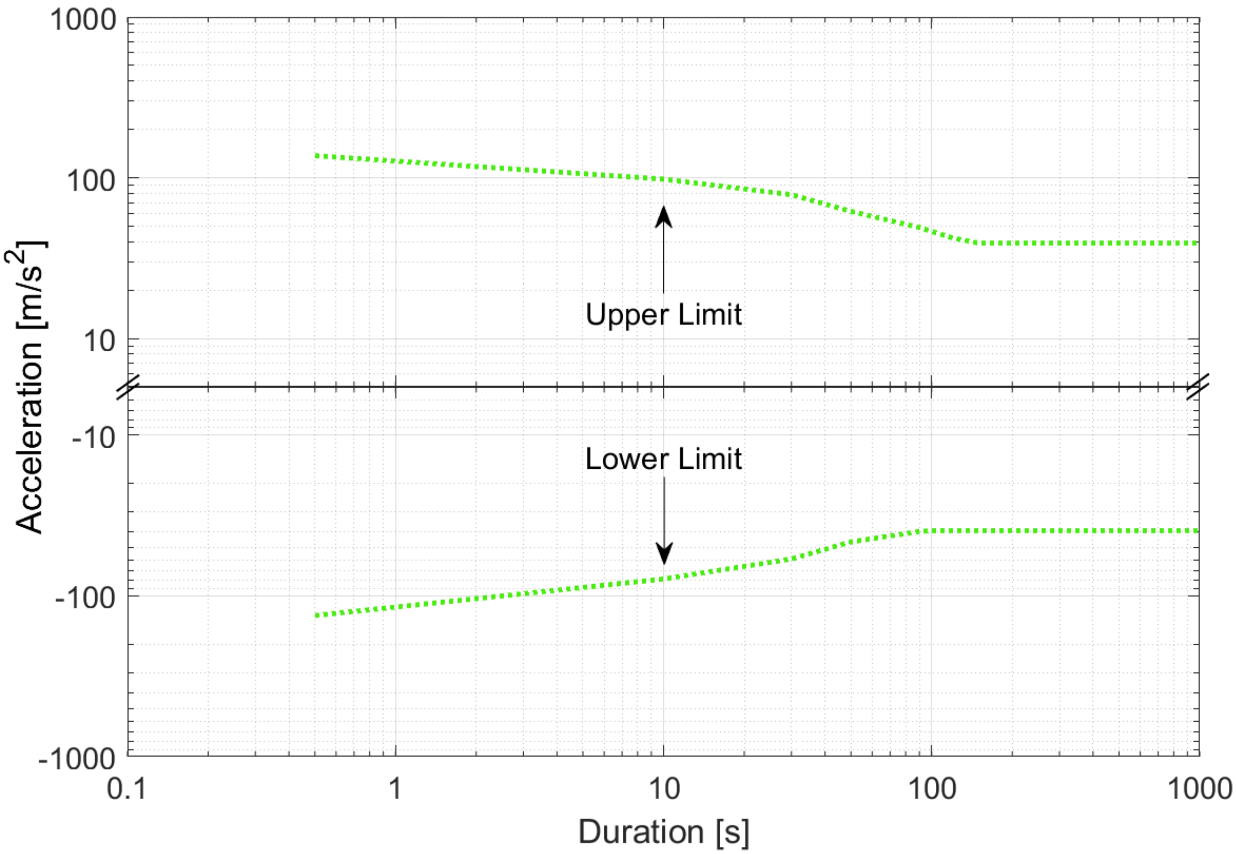


Figure 6.5-5—Ax Sustained Translational Acceleration Limits (Standing)

Table 6.5-5—Ay Sustained Translational Acceleration Limits (Standing)
Acceleration limits for deconditioned crew (standing)

Upper limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	19.6	9.81	9.81
Lower limit	Duration [s]	0.5	100	10000
	Acceleration [m/s^2]	-19.6	-9.81	-9.81

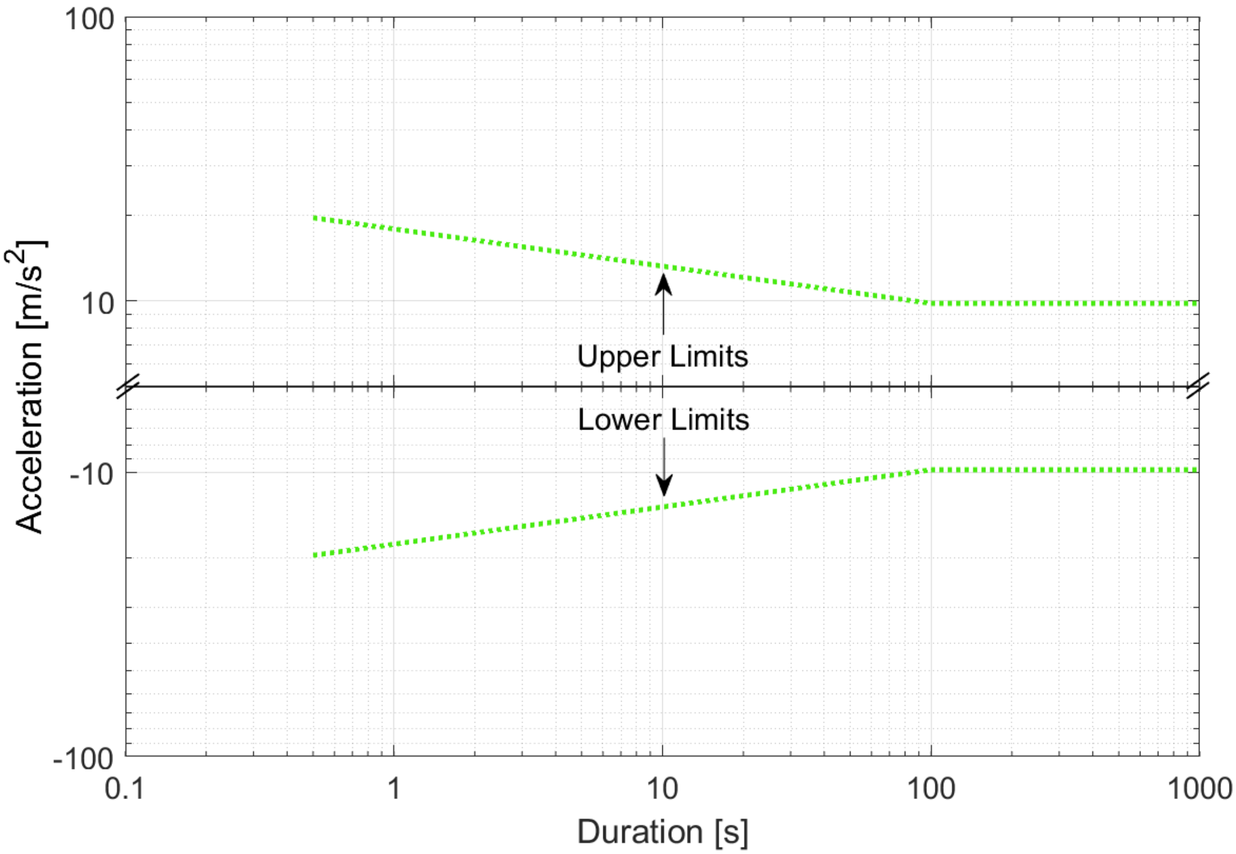


Figure 6.5-6—Ay Sustained Translational Acceleration Limits (Standing)

Table 6.5-6—Az Sustained Translational Acceleration Limits (Standing)

Acceleration limits for non-deconditioned crew (standing)

Upper limit	Duration [s]	0.5	0.5 < t < 900	900	Sustained
	Acceleration [m/s²]	9.81	9.81	4.90	4.90
Lower limit	Duration [s]	0.5	Sustained		
	Acceleration [m/s²]	-0.5	-0.5		

Acceleration limits for deconditioned crew (standing)

Upper limit	Duration [s]	0.5	30	50	80	100	120	Sustained
	Acceleration [m/s²]	9.81	9.81	7.85	6.67	5.88	4.90	4.90
Lower limit	Duration [s]	0.5	Sustained					
	Acceleration [m/s²]	-0.5	-0.5					

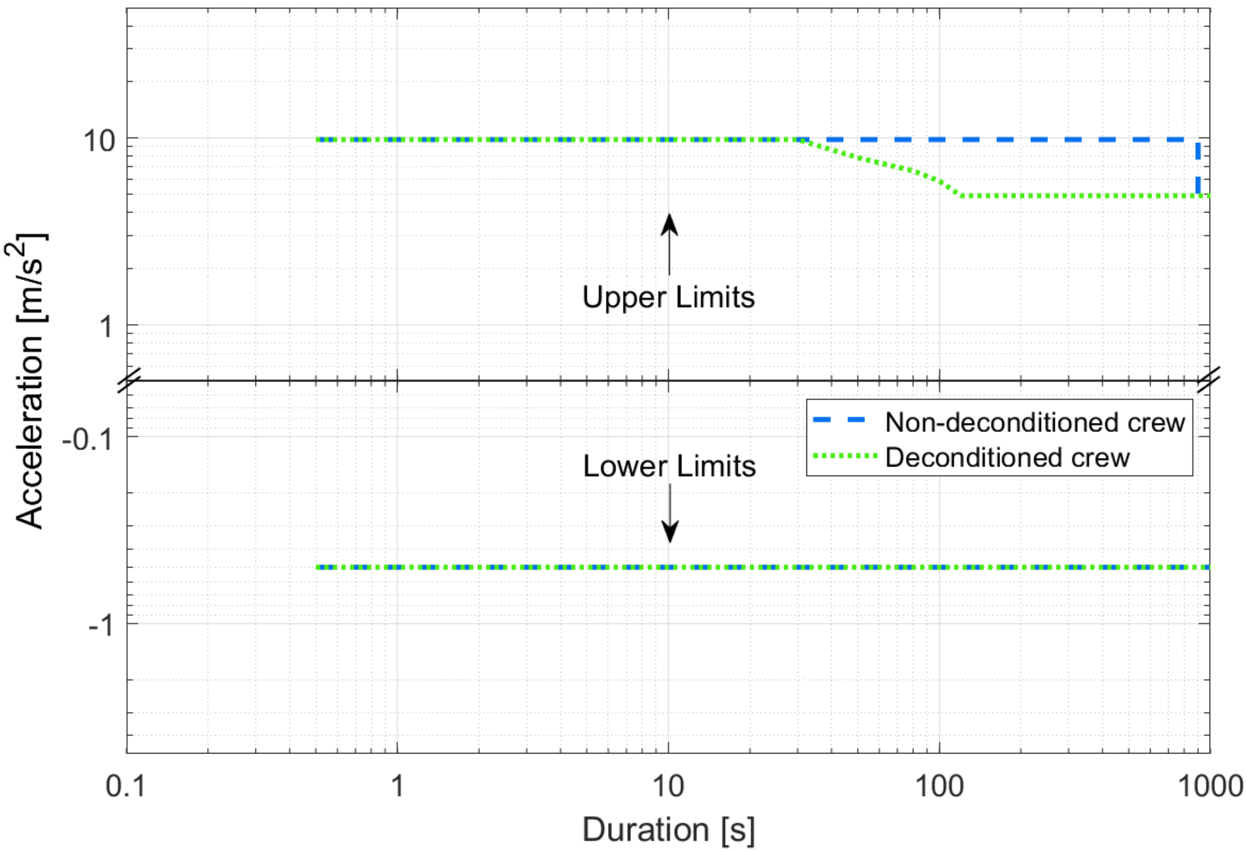


Figure 6.5-7—Az Sustained Translational Acceleration Limits (Standing)

6.5.2 Rotation Limits

6.5.2.1 Rotational Velocity

[V2 6065] The system **shall** limit crew exposure to rotational velocities in yaw, pitch, and roll by staying below the limits specified in Figure 6.5-8—Rotational Velocity Limits and Table 6.5-7—Rotational Velocity Limits.

[Rationale: The limits in this figure represent safe levels of sustained rotational acceleration for crewmembers under nominal and off-nominal conditions. Exposure to rotational acceleration above these limits could significantly affect human performance for maneuvering and interacting with a spacecraft. The limits for deconditioned crewmembers are lower because crewmembers are expected to have degraded capabilities due to deconditioning from exposure to reduced gravity. For emergency conditions, limits are higher because it may be necessary to expose the crew to accelerations more severe than those experienced nominally. Humans are never to be exposed to rotational acceleration rates greater than these elevated limits as this significantly increases the risk of incapacitation, thereby threatening crew survival.]

Table 6.5-7—Rotational Velocity Limits
Data for Curves

Emergency conditions	Duration [s]	0.5	1	700
	Rotational Velocity [rad/s]	14	13	6.3
Non-deconditioned crew	Duration [s]	0.5	1	700
	Rotational Velocity [rad/s]	6.6	5.2	0.63
Deconditioned crew	Duration [s]	0.5	1	700
	Rotational Velocity [rad/s]	4.9	3.9	0.47

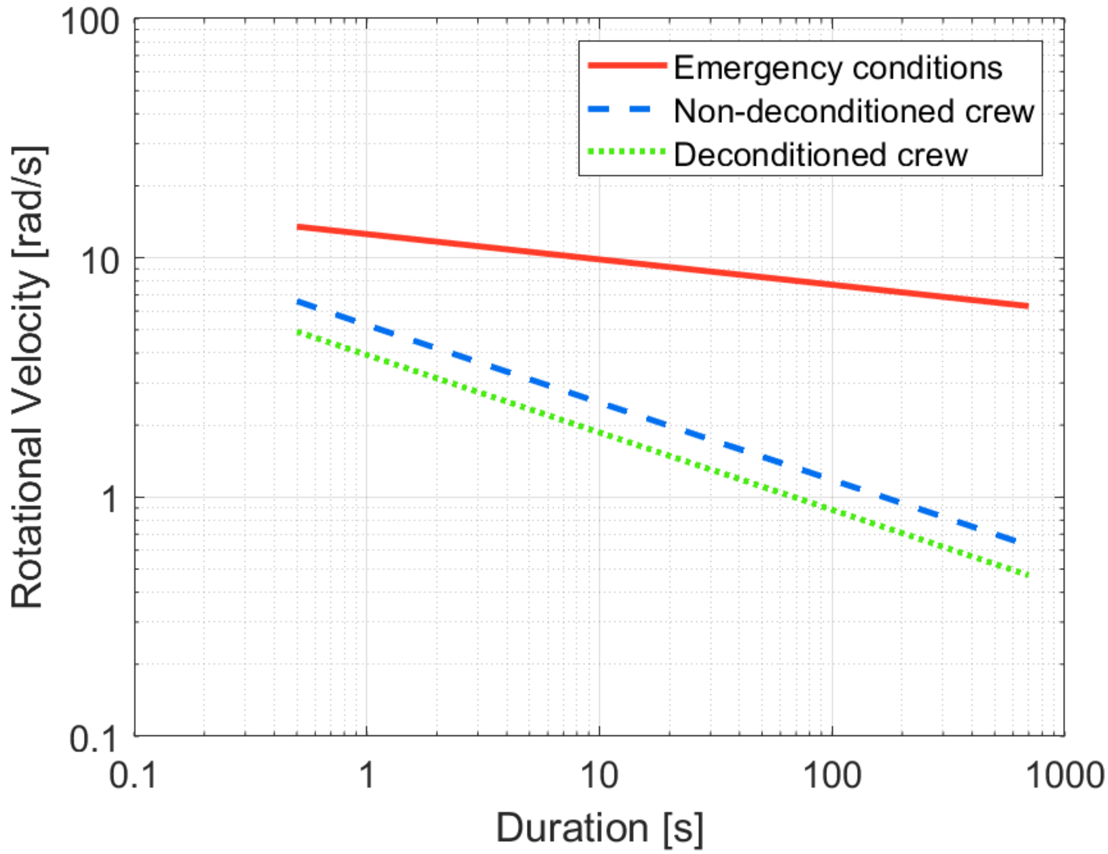


Figure 6.5-8—Rotational Velocity Limits

6.5.2.2 Sustained Rotational Acceleration Due to Cross-Coupled Rotation

[V2 6066] The system **shall** prevent the crew exposure to sustained (> 0.5 second) rotational accelerations caused by cross-coupled rotations greater than 2 rad/s^2.

[Rationale: Crewmembers are not expected to be able to tolerate sustained cross-coupled rotational accelerations (simultaneous rotations about two different axes) in excess of 2 rad/s^2 without significant discomfort and disorientation. Sustained cross-coupled rotational accelerations exceeding this amount have been found to significantly impact human performance and autonomic function (e.g., nausea, dizziness, and disorientation; degradations in neurovestibular and sensorimotor performance, physical reach, and cognition), potentially for

an extended period of time after exposure. Note that rotational acceleration due to cross-coupled rotation can be computed for rotational velocity components represented in any vehicle- or head-referenced coordinate frame. Ideally, rotational velocities are decomposed into their orthogonal principal components before computing the acceleration due to cross-product terms. For scientific references regarding this subject, see chapter 6, Natural and Induced Environments, of the Human Integration Design Handbook (HIDH).]

6.5.2.3 Transient Rotational Acceleration

[V2 6067] The system **shall** limit transient (≤0.5 seconds) rotational accelerations in yaw, pitch, or roll as specified in Table 6.5-8—Head CG Rotational Acceleration Limits, to which the crew is exposed. The limits are appropriately scaled for each crewmember size from the 50th percentile male limits of 2,200 rad/s^2 for nominal and 3,800 rad/s^2 for off-nominal cases.

[Rationale: Crewmembers are not expected to be able to tolerate sustained rotational accelerations in excess of 2,200 rad/s^2 for nominal and 3,800 rad/s^2 for off nominal cases for a 50th percentile male. This could occur as a result of an impact, whereby brief, high-magnitude rotational accelerations are imparted to the crew. These values relate to a risk of 5% or 19% risk of brain injury, respectively, for a 50th percentile male. These values are to be appropriately scaled to other crewmember sizes as needed. For additional information scaling these limits, see Petitjean, A., et al. (2015). Normalization and Scaling for Human Response Corridors and Development of Injury Risk Curves. Accidental Injury: Biomechanics and Prevention. N. Yoganadan, A. Nahum and J. Melvin. New York, Springer Science+Business Media: 769-792.]

Table 6.5-8—Head CG Rotational Acceleration Limits

Head CG Rotational Acceleration [rad/s^2]	Nominal			Off-Nominal		
	Small Female	Mid-size Male	Large Male	Small Female	Mid-size Male	Large Male
	2500	2200	2100	4200	3800	3600

6.5.3 Acceleration Injury Prevention

[V2 6069] The system **shall** mitigate the risk of injury to crewmembers caused by accelerations during dynamic mission phases per Table 6.5-9—Acceptable Injury Risk Due to Dynamic Loads.

[Rationale: During dynamic flight phases, there is potential for impact and flail injury, which includes crewmember extremities impacting vehicular surfaces or objects, hyperextending, hyper-flexing, hyper-rotating, fracturing, or dislocating if proper restraints and supports are not used. Features such as harnesses, form-fitting seats, and tethers may help maintain the proper position of the crewmember's body and limbs to reduce movement or contact with vehicle surfaces that would produce injury. In addition, the design of spacesuits may contribute to reducing injury to the crew. Preventing the inadvertent contact of extremities with vehicular structure or interior components significantly reduces the likelihood of limb fracture or soft

tissue injury during a dynamic flight event. Extremity guards, tethers, garters, and handholds have been used to reduce injury in other spacecraft, aircraft, and automotive vehicles. Injury classifications are based on the Operationally Relevant Injury Scale defined in NASA/TM-2014-217383, Defining NASA Risk Guidelines for Capsule-based Spacecraft Occupant Injuries Resulting from Launch, Abort, and Landing. Occurrence of dynamic cases identified in Table 6.5-9—Acceptable Injury Risk Due to Dynamic Loads are based on statistical modeling of possible dynamic events. See NASA/TM-2014-217383 for more information. For example, during the reentry of Space Transportation System (STS)-107, the crew had notable flail injuries in their extremities, upper body, and head from the dynamic accelerations and motions that were determined to be a lethal event. Contributing factors to this involved both inertial reels from the seat belts and the helmet when the crew were exposed to cyclical motions. The seat belt inertial reel mechanisms failed, which resulted in crew body flail. The helmets did not conform to crew head, which resulted in lethal head injuries when exposed to cyclical forces.]

Table 6.5-9—Acceptable Injury Risk Due to Dynamic Loads

Injury Severity (Class)*	≥95% of dynamic cases	<5% of dynamic cases
Minor (I)	<4%	<23%
Moderate (II)	<1%	<4%
Severe (III)	<0.1%	<0.7% [<1%]□
Life-Threatening/Fatal (IV)	<0.1%	<0.7%

**Injury classes are defined in NASA/TM-2014-217383.*
□Acceptance of higher occurrence in brackets assumes Search and Rescue forces are able to access crewmembers within 30 minutes of mishap occurrence.

6.5.4 Injury Risk Criterion

[V2 6070] The system **shall** limit crew exposure to transient translational acceleration (≤0.5 seconds) by limiting the injury risk criterion (β/beta) to no greater than 1.0 (Low) for seated or standing crew as defined by Dynamic Response (DR) limits in NASA/TM-20205008198 Table 2 "Updated Dynamic Response Limits for Standing", while crew are restrained as required in NASA/TM-2013-217380REV1 for seated crew, or NASA/TM – 20205008198 for standing crew.

[Rationale: The Brinkley Dynamic Response model will provide an injury risk assessment during dynamic phases of flight for accelerations <0.5 second. Application of this model assumes that a crewmember will be similarly restrained during all events where the Brinkley model is applied. Human tolerance for injury risk limits for development of space vehicles that are based on human volunteer impact test data and operational emergency escape system

experience such as the Brinkley criterion have been adjusted for landing impact after reentry considering existing knowledge of physiological deconditioning related to long-term exposure to the microgravity of space. The vast experience in human testing of aircraft ejection seats and operational experience with emergency escape systems have enabled the highest fidelity for injury prediction, using the Brinkley model in the Az axis. Although the maximum allowable Brinkley β value is 1.0 for any given level of risk, the vehicle occupant protection system design is to strive to achieve β values as low as reasonably achievable for as many of the landing conditions and scenarios as possible. The criteria include dynamic response limits that have been established for varying probabilities of injury. This model may be used primarily for landing scenarios, but it is applicable for all dynamic phases of flight for accelerations less than 0.5 second. Application of the Brinkley Dynamic Response model is described in NASA/TM-2013-217380REV1. Structural failure may present an occupant protection hazard through impinging upon occupant volume in such a way as to injure crewmembers.

The threshold for what constitutes standing posture is less than 80% of the total +Az axis force being transmitted through the crewmember's buttock and thighs. Crewmembers in a standing posture without the protections offered by a seat or similar support structure will have lower tolerance to transient acceleration. Lower acceleration limits have been established to account for the risk of injury to the lower extremities. For transient accelerations occurring more than 30 days mission elapsed time, a lower limit is specified to account for spaceflight deconditioning effects on injury tolerance. These additional limits assume additional equipment mass, such as the spacesuit, borne by the crewmember is less than 20% of the crewmember's shirtsleeve mass. They also assume sufficient extremity and torso restraints to prevent flail and motion that could result in further injury not accounted for by the reduced limits. It is assumed that the primary direction of loading will be in +Az direction for the standing posture, and that the crewmember will remain in an upright orientation during the dynamic event, as it assumed the load would be primarily in the +Az direction. The limits specified in NASA/TM-20205008198, Table 2 "Updated Dynamic Response Limits for Standing" are only valid if the restraint configuration prevents the crewmember from losing balance during the dynamic event.]

6.5.5 Dynamic Mission Phases Monitoring and Analysis

[V2 6111] The system **shall** collect vehicle and crewmember acceleration parameters, specific kinematic responses, and associated metadata, during all dynamic mission phases and suited operations (defined as ascent, abort, entry, descent, landing, postlanding, and EVA operations) to correlate with any injuries incurred by crewmembers.

[Rationale: Systems are to be capable of monitoring the vehicle and crewmember-specific acceleration levels and associated crewmember kinematic responses (e.g., in-cabin video, crewmember-worn accelerometry, suit instrumentation) during dynamic mission phases to correlate with any crewmember injuries. This assessment is critical to understanding the loads imparted to the human to: 1) aid in the assessment of any injuries incurred; 2) predict and correct harmful conditions before they occur; and 3) identify appropriate design changes to minimize injuries on future flights/vehicles. This data is also critical to inform modeling and analysis capabilities for future vehicles. The collection of associated metadata will enable

mitigation of risks associated with dynamic mission phases, including the ability of the crew to egress during off-nominal events. Such metadata may include, but is not limited to: Vehicle-related data such as vehicle position at landing (upright/side-lying/inverted), cabin temperature and humidity, duration of crew egress from the vehicle, and any anomalies that occurred during the dynamic phase (e.g., toxin leaks, hardware/software failures, etc.); environmental data such as wave height for water landings, time of day, and weather conditions; and physiological data such as percentage of crew with nausea/vomiting, crew fatigue and fitness level, crew postlanding task performance data, and any injuries or close-calls. Accelerometers and other sensors can be located in the suit, in the seat, or elsewhere in the vehicle.]

6.5.6 Hang Time Limit

[V2 6112] The system **shall** limit crew exposure to suspension trauma conditions to seven minutes or less.

[Rationale: The hang time tolerance limit of seven minutes was chosen to protect the crew from a variety of life-threatening post landing complications when their vehicle lands in an inverted posture. This time limit reduces the probability the crew will experience suspension trauma symptoms. Suspension trauma, or harness hang syndrome, is the closest comparable terrestrial condition to the crew hanging in an inverted seated position. Spaceflight medicine literature review identified that cognitive deficits could occur within three and a half minutes for a deconditioned crew, affecting their ability to take action if required. They also concluded that uprighting must be complete within seven minutes to prevent a decrease in blood pressure and loss of consciousness to the crew. This could be met through a variety of mechanisms in addition to uprighting, such as allowing crewmember seat egress. See Barr, Y & Fogarty, J (2010). Assessment of Prone Positioning of Restrained, Seated Crewmembers in a Post Landing Stable 2 Orion Configuration, JSC-CN-19414.]

6.5.7 Crew Limits in Launch Orientation

[V2 6113] The time in which crewmembers are on back with feet elevated in a launch configuration **shall not** exceed 3 hours and 15 minutes, excluding subsequent safing and egress time.

[Rationale: This position can be extremely fatiguing, painful, and cause musculoskeletal discomfort and difficulty urinating. These effects have the potential to impair a crewmember's ability to perform launch duties, emergency egress procedures, and post launch tasks, and, coupled with the length of the crew day, can also affect cognitive performance. The time interval ends with lift-off. The "crew time on back" is the period from the first crewmember's adoption of an on-back posture until launch or, in the event of a scrub, until vehicle safing begins. This time accounts for crew ingress and hold time leading to the planned launch time. It does not include vehicle safing or egress time.]

6.5.8 Extraterrestrial Surface Transport Vehicles

Crewmembers will experience accelerations and dynamic loads while operating or traversing in an extraterrestrial surface transport vehicle (ESTV). Considerations must be taken to ensure crew health and safety in these circumstances.

6.5.8.1 Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits

[V2 6154] The extraterrestrial surface transport vehicle (ESTV) system **shall** limit the magnitude of crewmember exposure to sustained (>0.5 seconds) translational acceleration by staying below the limits in Table 6.5-10—Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits, which specify the ±Ax, ±Ay, and ±Az translational acceleration limits appropriate for specific restraint conditions.

[Rationale: When addressing the sustained translational acceleration limits, several considerations and general assumptions have been made. Further information can be found in NASA/TM-20220011974 Lunar Transport Vehicle Occupant Protection Requirements. These limits in Table 6.5-10—Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits assume no intra-suit restraints other than a standard harness as seen in previous iterations of the EMU-style suit configurations. Additional occupant restraints in the form of inserts and suit modifications were not considered. With the existing suit designs at NASA, there are insufficient head and neck restraints to qualify for NASA Category 4 (K0000370695-GEN) acceleration limits.

In addition to crew health limits, the accelerations must permit the occupant to meet performance requirements. The occupant must be able to interface with the ESTV to operate the vehicle and read any instrumentation while traversing the extraterrestrial surface.

It is assumed that the vehicle shall provide proper foot restraints and back support in the proposed design and shall have an occupant envelope to restrict the crew from contacting each other laterally.

The limits in Table 6.5-10 represent safe levels of sustained translational acceleration under nominal and off-nominal conditions. Exposure to accelerations above these limits could create a risk of occupant injury and significantly affect human performance for maneuvering and interacting with the human transport vehicle. The physics of the environment will limit the exposure duration to Az making the specified limits acceptable. The Ax and Ay limits must be met by a combination of vehicle design and conops (planned time versus distance of vehicle transits taking into consideration the traversed extraterrestrial terrain) which will limit exposure magnitude and duration.

These limits cover all accelerations imposed on the crewmember both directly by the human transport vehicle as well as indirectly by the ESTV through the suit.

Design solutions are expected to contain energy attenuation to mitigate the accelerations the crewmember is subjected to.

Any induced linear acceleration from rotation is subject to this requirement and must be verified.]

Table 6.5-10—Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits

Acceleration Vector	Lap & Shoulder Restraint	Rigid HUT Attachment	
	Seated	Seated	Standing
+x	$Ax \leq 39.24 m/s^2$	$Ax \leq 39.24 m/s^2$	$Ax \leq 39.24 m/s^2$
-x	$Ax \geq -19.62 m/s^2$	$Ax \geq -19.62 m/s^2$	$Ax \geq -19.62 m/s^2$
±y	$\|Ay\| \leq 9.81 m/s^2$	$\|Ay\| \leq 9.81 m/s^2$	$\|Ay\| \leq 9.81 m/s^2$
+z	$Az \leq 19.62 m/s^2$	$Az \leq 19.62 m/s^2$	$Az \leq 9.81 m/s^2$ *
-z	$Az \geq -4.9 m/s^2$ if time < 30s $Az > 0 m/s^2$ if time ≥ 30s	$Az \geq -4.9 m/s^2$ if time < 30s $Az > 0 m/s^2$ if time ≥ 30s	$Az \geq -1.57 m/s^2$ *
** Assumes occupant has had time to adjust to extraterrestrial gravity*			

6.5.8.2 Extraterrestrial Surface Transport Vehicle Translation Jerk Limits

[V2 6155] The extraterrestrial surface transport vehicle (ESTV) system **shall** limit the crewmember exposure to translational jerk to the limits given in Table 6.5-11—Extraterrestrial Surface Transport Vehicle Translation Jerk Limits, which specifies the $\pm A_x$, $\pm A_y$, and $\pm A_z$ translational jerk limits appropriate for specific restraint conditions.

[Rationale: When addressing the sustained translational jerk limits, several considerations and general assumptions have been made. Further information can be found in NASA/TM-20220011974 Lunar Transport Vehicle Occupant Protection Requirements. These limits in Table 6.5-11—Extraterrestrial Surface Transport Vehicle Translation Jerk Limits assume no intra-suit restraints other than a standard harness as seen in previous iterations of the EMU-style suit configurations. Additional occupant restraints in the form of inserts and suit modifications were not considered. With the existing suit designs at NASA, there are insufficient head and neck restraints to qualify for NASA Category 4 (K0000370695-GEN) jerk limits.

Following ASTM F2291-18 guidance, the jerk limits were obtained by taking the differences between the +/- acceleration limits for the corresponding NASA Category in the acceleration table and dividing the difference by the respective body axis's minimum onset duration (200ms for x and y axes, 133ms for z axis).

In addition to crew health limits, the experienced jerk must permit the occupant to meet performance requirements. The occupant must be able to interface with the ESTV to operate the vehicle and read any instrumentation while traversing the surface.

It is assumed that the vehicle shall provide proper foot restraints and back support in the proposed design and shall have an occupant envelope to restrict the crew from contacting each other laterally.

The limits in Table 6.5-11 represent safe levels of translational jerk under nominal and off-nominal conditions. Exposure to jerk above these limits could create a risk of occupant injury in the human transport vehicle. The limits must be met by a combination of vehicle design (e.g., shock absorbers) and conops (planned time versus distance of vehicle transits taking into consideration the traversed extraterrestrial terrain).

These limits cover all jerk imposed on the crewmember both directly by the ESTV as well as indirectly by the ESTV through the suit.

Design solutions are expected to contain energy attenuation to mitigate the jerk the crewmember is subjected to.]

Table 6.5-11—Extraterrestrial Surface Transport Vehicle Translation Jerk Limits

Jerk Vector	Lap & Shoulder Restraint	Rigid HUT Attachment	
	Seated	Seated	Standing
dAx/dt	294m/s^3	294m/s^3	294m/s^3
dAy/dt	98m/s^3	98m/s^3	98m/s^3
dAz/dt	196m/s^3	196m/s^3	98m/s^3

6.5.8.3 Blunt Trauma Limits for Enabling Performance

[V2 6156] The system **shall** limit the crewmember exposure to blunt trauma forces to the limits given in Figure 6.5-9—Performance Blunt Force Maximum Allowable Depth of Compression Limits (Seated or Standing Vehicle Occupants), which specifies the maximum allowable depth of compression across the occupant body (seated or standing), and below 18 pounds-force (lbf) across skeletal locations of concern outlined in Figure 6.5-10—Anthropometric Locations for Blunt Trauma Limits & Skeletal Locations of Concern:

a. Manubrium of the Sternum – Point 1

b. Sternum (body) – Point 2

c. Clavicle – Points 10 & 11

d. Lateral aspect of the thorax – Points 22 & 23

e. Vertebral Column – Points 40, 41, & 42

f. Cervical Spine (C7) – Point 48

g. Scapula – Point 31

h. Spine – Point 39

i. Acromion Process – Point 49

j. Elbow (olecranon process) – Point 61

[Rationale: Meeting this requirement will enable performance, however the crewmember may experience minor discomfort that does not require first aid or medical attention. This requirement was initially developed for extraterrestrial surface transport vehicles but may apply to a wider range of systems (launch vehicles, elevators, landers etc.) if deemed applicable.

When addressing the blunt force limits, several considerations and general assumptions have been made. Further information can be found in NASA/TM-20220011974 Lunar Transport Vehicle Occupant Protection Requirements. These limits in Figure 6.5-12—Performance Blunt Force Maximum Allowable Depth of Compression Limits (Seated or Standing Vehicle Occupants), assume no intra-suit restraints other than a standard harness as seen in previous iterations of the EMU-style suit configurations. Additional occupant restraints in the form of inserts and suit modifications were not considered.

It is assumed that the vehicle shall provide proper foot restraints and back support in the proposed design. The vehicle occupant is also assumed to always remain in contact with supporting surfaces.

These limits cover all blunt forces imposed on the crewmember both directly by the system as well as indirectly by the system through a suit.

Design solutions are expected to contain energy attenuation to mitigate the blunt force the crewmember is subjected to.]

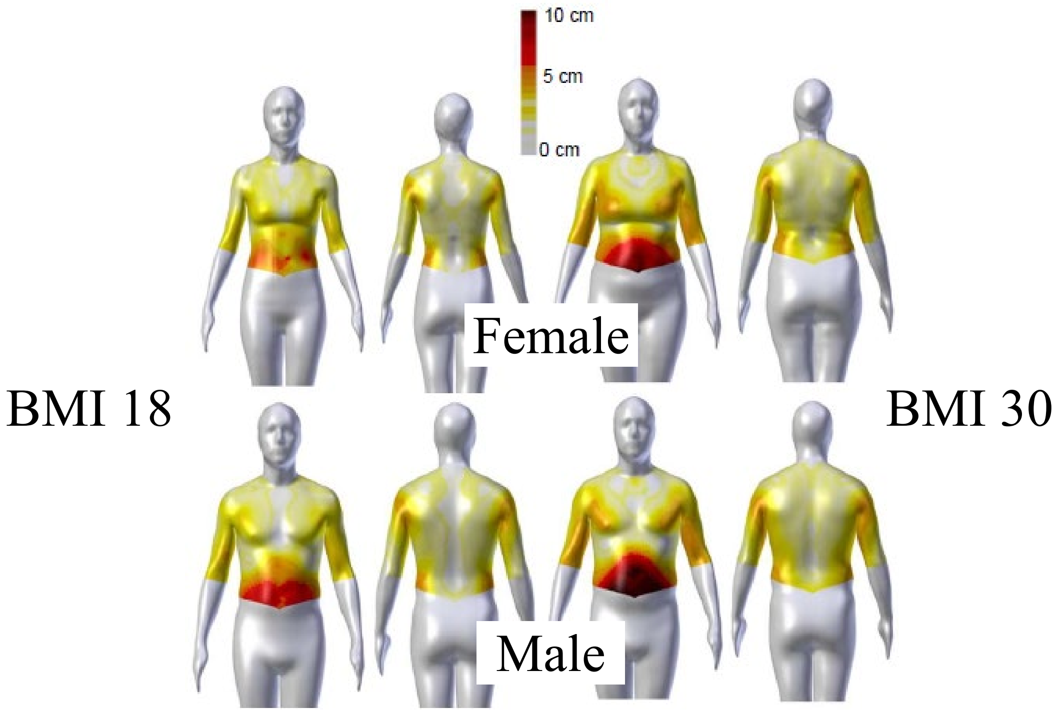


Figure 6.5-9—Performance Blunt Force Maximum Allowable Depth of Compression Limits (Seated or Standing Vehicle Occupants)

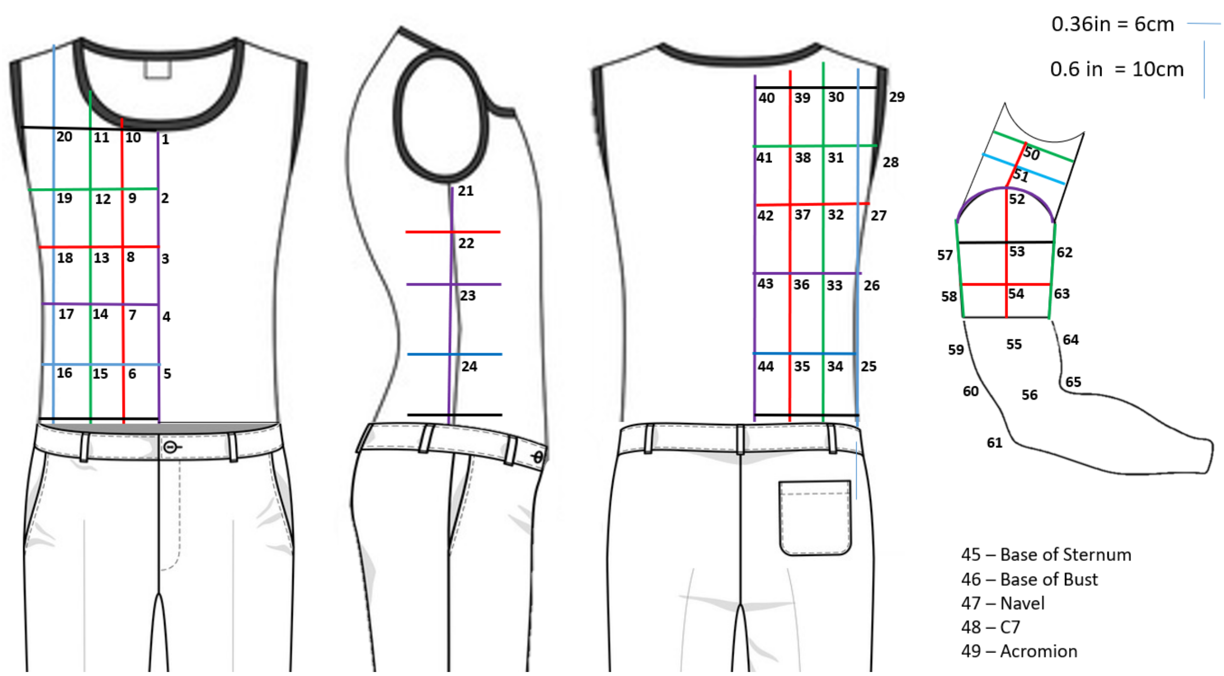


Figure 6.5-10—Anthropometric Locations for Blunt Trauma Limits & Skeletal Locations of Concern

6.6 Acoustics

This section establishes requirements to ensure an acceptable acoustic environment to preclude noise-related hearing loss and interference with communications and to support human performance. For technical requirements using sound to relay information, see section 10.5.1 Audio Systems, in this NASA Technical Standard. Table 6.6-1—Acoustic Limits for Launch, Entry, and Abort Phases, and Table 6.6-2—Acoustic Limits for On-Orbit, Lunar, and Planetary Operations Phase are summaries of the acoustic requirements listed in the following sections, referenced by requirement number.

To ensure that an integrated vehicle (including suit systems) meets the acoustic limits, it is necessary to develop an Acoustic Noise Control Plan that establishes the overall noise control strategy, acoustic limit allocations, acoustic testing, analyses, remedial action steps, schedule, and follow-up activities. This plan needs to be initially released early in the design cycle and then updated as new data and design information become available. The included acoustic limit allocations would define a set of allocated and sub-allocated acoustic limits for systems, sub-systems, and hardware components so that the total contributions of all hardware will result in compliance with this NASA Technical Standard. As part of the Acoustic Noise Control Plan, it is best practice to verify acoustic requirements with test of the actual flight hardware. Modeling the acoustic environment of the vehicle with measured noise sources and propagation paths is best practice. Small design changes or even different part numbers of the same design such as with fans can change the acoustic level. Previous spaceflight experience has shown that without such a plan, it is difficult to develop an integrated system that can meet acoustic limits.

In this section there are cases that allow for or restrict the use of hearing protection to meet requirements. In cases where hearing protection is allowed, the phrase "at crewmember's ear" is used. For cases where hearing protection cannot be used to satisfy these requirements, the phrase "at crew member's head" is used. The allowance or restriction of hearing protection in each case is called out in the requirement or in the rationale.

Table 6.6-1—Acoustic Limits for Launch, Entry, and Abort Phases

Mission Phase	24-Hour Hazardous Noise Exposure Limits	Ceiling	Impulse Noise	Infrasonic Noise 1-20 Hz	Referenced Requirements
Launch	Noise dose <100, equivalent to 8-hour 85 dBA TWA	≤105 dBA allows 10 dBA headroom for Personal Audio	≤140 dB peak SPL[†]	<150 dB*	V2 6073; V2 6074; V2 6076; V2 6085
Entry	Noise dose ≤100, equivalent to 8-hour 85 dBA TWA	≤105 dBA allows 10 dBA headroom for Personal Audio	≤140 dB peak SPL	<150 dB*	V2 6073; V2 6074; V2 6076; V2 6085
Launch Abort	Noise dose ≤100, equivalent to 8-hour 85 dBA TWA	≤115 dBA	≤140 dB peak SPL	< 150 dB*	V2 6073; V2 6075; V2 6076; V2 6085
Personal Audio including alarms* **	N/A	≤115 dBA	≤140 dB peak SPL	N/A	V2 6073; V2 6076; V2 6081; V2 6083; V2 6106

**Hearing protection CANNOT be used to satisfy this limit*
***Applies to all mission phases*
[†] Sound Pressure Level

Table 6.6-2—Acoustic Limits for On-Orbit, Lunar, and Planetary Operations Phase*

Mission Phase	24-Hour Hazardous Noise Exposure Limits	Continuous Noise	Hazardous Noise	Intermittent Noise	Impulse Noise	Referenced Requirements
On-Orbit	Noise dose ≤100, equivalent to 8-hour 75 dBA TWA	NC-50 Octave Band SPL limits. See Figure 9 and Table 8	<85 dBA	Specified Sound Level (dBA) depending on duration, see Table 6	≤140 dB peak SPL	V2 6077; V2 6078; V2 6080; V2 6083
a. For Sleep on Missions >30 days	Noise dose ≤100, equivalent to 8-hour 75 dBA TWA	NC-40 Octave Band SPL limits. See Figure 9 and Table 8	<85 dBA	+10 dBA or less above background	+10 dB peak or less above background	V2 6077; V2 6079; V2 6082
b. For Sleep on Missions ≤30 days	Noise dose ≤100, equivalent to 8-hour 75 dBA TWA	NC-50 Octave Band SPL limits. See Figure 9 and Table 8	<85 dBA	+10 dBA or less above background	+10 dB peak or less above background	V2 6077; V2 6078; V2 6079; V2 6082
Personal Audio	N/A	N/A	<115 dBA	N/A	N/A	V2 6106
Broadcast Alarms	N/A	N/A	<95 dBA	N/A	N/A	V2 6081

**Hearing protection CANNOT be used to satisfy these limits.*

6.6.1 Acoustic Limits

6.6.1.1 Launch, Entry, and Abort Noise Exposure Limits

[V2 6073] During launch, entry, and abort operations, the noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, **shall** be limited such that the noise dose (D) is ≤100:

$$D = 100\sum_{n=1}^{N}\frac{C_n}{T_n}\text{, where:}$$

N = the number of noise exposure events during the 24-hour period
Cn = the actual duration of the exposure event in minutes
Tn = the maximum noise exposure duration allowed, based on the specific sound level (Ln) of an exposure event in dBA, calculated using the following equation:

$$T_n = \frac{480}{2^{\left(\frac{Ln-85}{3}\right)}}$$

[Rationale: A noise dose of D = 100 is equivalent to an 8-hour, 85 dBA time-weighted average (TWA) using a 3 dB exchange rate. Equivalent noise exposure levels above 85 dBA for more than 8 hours have been shown to increase the risk of noise-induced hearing loss. The above formulae can be used to calculate the 24-hour noise exposure levels based on the 8-hour, 85 dBA criteria recommended by National Institute for Occupational Safety and Health (NIOSH), using the 3 dB exchange rate. The noise attenuation effectiveness of hearing protection, suit and helmet or communications headsets may be used to satisfy this requirement. Any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Requirements established to meet this requirement are to be included in the Acoustic Noise Control Plan. The Acoustic Noise Control Plan allocates noise levels to individual components and is maintained to ensure that the total system meets the levels defined in this NASA Technical Standard.]

6.6.1.2 Ceiling Limit for Launch and Entry

[V2 6074] During launch and entry operations, the system **shall** limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 105 dBA.

[Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. In cases where audio communications are required, e.g., launch, entry, a 105 dBA limit is recommended to allow 10 dB of headroom for critical alarms and voice communications without exceeding the ultimate 115 dBA ceiling limit. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement; however, any planned use of hearing protection is to be well documented and approved. Program requirements established to meet this technical requirement are to be included in the Acoustic Noise Control Plan. This technical requirement does not apply to impulse noise sources.]

6.6.1.3 Ceiling Limit for Launch Abort

[V2 6075] During launch abort operations, the system **shall** limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 115 dBA.

[Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. In cases where no audio communications are required, e.g., during abort operations, there is no need to allow 10 dB of headroom for alarms and voice communications. The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement; however, any planned use of hearing protection is to be well documented and approved.]

6.6.1.4 Launch, Entry, and Abort Impulse Noise Limits

[V2 6076] During launch, entry, and abort operations, impulse noise measured at the crewmember's ear location **shall** be limited to less than 140 dB peak SPL.

[Rationale: A limit of 140 dB peak SPL for impulse noise prevents trauma to the hearing organs caused by impulse noise (OSHA 29 CFR 1910.95, Para 1910.95(b)(2) and WHO Environmental Health Criteria 12 – NOISE, Para 3.1.3). The noise attenuation effectiveness of hearing protection or communications headsets may be used to satisfy this requirement, however any planned use of hearing protection to satisfy this requirement is to be well documented and approved. Program requirements established to meet this technical requirement are to be included in the Acoustic Noise Control Plan.]

6.6.1.5 Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort

[V2 6077] For off-nominal operations, broadcast communications, pressurization valve noise, and maintenance activities, the A-weighted sound level (excluding impulse noise and alarm signals) **shall** be less than 85 dBA (using fast exponential-time-averaging), regardless of the measured time interval; except in the case of pressurization valve noise, the noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.

[Rationale: The 85 dBA overall SPL defines the hazardous noise limit during all phases except launch, entry, and abort, at which action to reduce the noise level is to be taken so that interference with voice communications and alarms, as well as increased risk for hearing loss, does not occur. This is to help ensure that the habitable volume is safe. This is not intended for nominal hardware emissions but to limit the sound level of sources such as communications systems, depressurization valves, and levels that occur during planned off-nominal operations and maintenance activities. Nominal on-orbit acoustic levels are limited by requirements [V2 6078] Continuous Noise Limits and [V2 6080] Intermittent Noise Limits of this NASA Technical Standard. This requirement does not apply to impulse noise sources.]

6.6.1.6 24-Hour Noise Exposure Limits

[V2 6115] The noise exposure level (not including impulse noise) at the crewmember's head, calculated over any 24-hour period, except during launch, entry, and abort operations, **shall** be limited such that the noise dose (D) is ≤100:

$$D = 100 \sum_{n=1}^{N} \frac{C_n}{T_n}$$

where:

N = the number of noise exposure events during the 24-hour period
C_n = the actual duration of the exposure event in minutes
T_n = the maximum noise exposure duration allowed, based on the specific sound level

(Ln) of an exposure event in dBA, calculated using the following equation:

$$T_n = \frac{480}{2^{\left(\frac{L_n - 75}{3}\right)}}$$

[Rationale: A noise dose of D = 100 is equivalent to an 8-hour, 75 dBA time-weighted average (TWA) using a 3 dB exchange rate. Equivalent noise exposure levels above 75 dBA for more than 8 hours have been shown to increase the risk of noise-induced hearing loss. The above formulae can be used to calculate the 24-hour noise exposure levels based on the 8-hour, 75 dBA criterion recommended by the World Health Organization (WHO), using the 3 dB exchange rate, which corresponds to a 24-hour noise exposure level of 70 dBA or a 16-hour noise exposure level of 72 dBA. The noise attenuation effectiveness of hearing protection or communications headsets cannot be used to satisfy this requirement. Program requirements established to meet this technical requirement are to be included in the Acoustic Noise Control Plan. The Acoustic Noise Control Plan allocates noise levels to individual components and is maintained to ensure that the total noise exposure system meets the levels defined in this NASA Technical Standard.]

6.6.1.7 Continuous Noise Limits

[V2 6078] In spacecraft work areas, where good voice communications and habitability are required, SPLs of continuous noise (not including impulse or intermittent noise sources) **shall** be limited to the values given by the Noise Criterion (NC)-50 curve in Figure 6.6-1—NC Curves, and Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa; hearing protection cannot be used to satisfy this requirement.

[Rationale: NC-50 limits noise levels within the habitable volume to allow adequate voice communications and habitability during mission operations. The noise limit at 16 kHz does not appear in Figure 6.6-1 but is given in Table 6.6-3. SPLs for continuous noise do not apply to

alarms, communications, or noise experienced during maintenance activities. The corresponding spacesuit requirement is defined in requirement [V2 11009] Continuous Noise in Spacesuits, in this NASA Technical Standard.]

6.6.1.8 Crew Sleep Continuous Noise Limits

[V2 6079] For missions greater than 30 days, SPLs of continuous noise **shall** be limited to the values given by the NC-40 curve (see Figure 6.6-1—NC Curves, and Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa) in crew quarters and sleep areas. Hearing protection cannot be used to satisfy this requirement.

[Rationale: For a crewmember to relax the auditory system, a quiet environment is to be provided during crew sleep; the NC-40 limit provides adequate auditory rest. The noise limit at 16 kHz does not appear in Figure 6.6-1—NC Curves but is given in Table 6.6-3—Octave Band SPL Limits for Continuous Noise. For missions 30 days or less in duration (short-duration missions), acoustic levels during sleep are limited by the requirement [V2 6078] Continuous Noise Limits (NC-50). Intermittent and impulse noise during sleep are controlled by the requirement [V2 6082] Annoyance Noise Limits for Crew Sleep. Some crewmembers find that using hearing protection causes sleep disturbance.]

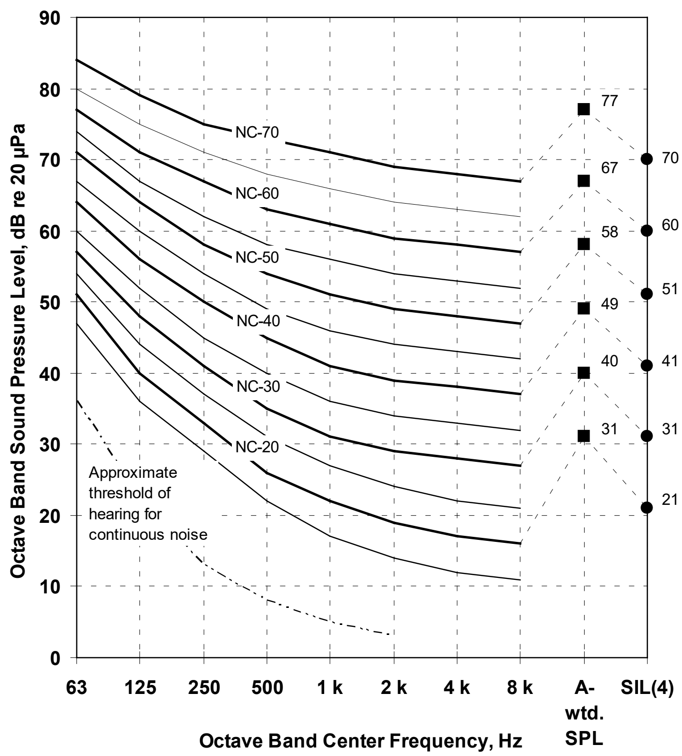


Figure 6.6-1—NC Curves

Note: Corresponding A-weighted SPLs and speech interference levels (SILs) are given for reference only (Beranek and Vér, 1992). SIL (4) is Speech Interference Level, 4-band method.

Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa

Octave Band Center Frequency (Hz)	63	125	250	500	1 k	2 k	4 k	8 k	16 k	NC
Work Areas Maximum (NC-50)	71	64	58	54	51	49	48	47	46	50
Sleep Areas Maximum (NC-40)	64	56	50	45	41	39	38	37	36	40

6.6.1.9 Intermittent Noise Limits

[V2 6080] For hardware items that operate for eight hours or less (i.e., intermittent noise), the maximum noise emissions (not including impulse noise), measured 0.6 m from the loudest hardware surface, **shall** be determined according to Table 6.6-4—Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for Any 24-hour Period (measured at 0.6 m distance from the source or closest distance to crew head, whichever is less). Hearing protection cannot be used to satisfy this requirement.

[Rationale: Table 6.6-4—Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for Any 24-hour Period limits crew exposure to intermittent noise levels of hardware items that are inherently noisy but that operate for short time periods. Intermittent sources can result in unacceptable noise levels, add to the overall crew noise exposure, impede communications, and cause disruption in crew rest/sleep.]

Table 6.6-4—Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for Any 24-Hour Period *(measured at 0.6 m distance from the source or closest distance to crew head, whichever is less)*

Maximum Noise Duration per 24-hr Period	Sound Pressure Level (dBA re 20 µPa)
8 hr	≤49
7 hr	≤50
6 hr	≤51
5 hr	≤52
4.5 hr	≤53
4 hr	≤54
3.5 hr	≤55
3 hr	≤57
2.5 hr	≤58
2 hr	≤60
1.5 hr	≤62
1 hr	≤65
30 min	≤69
15 min	≤72
5 min	≤76

Maximum Noise Duration per 24-hr Period	Sound Pressure Level (dBA re 20 µPa)
2 min	≤78
1 min	≤79
Not allowed *	≥80
** To leave a margin from the 85-dBA nominal hazardous noise limit*	

6.6.1.10 Alarm Maximum Sound Level Limit

[V2 6081] The maximum alarm signal A-weighted sound level **shall** be less than 95 dBA at the operating position of the intended receiver.

[Rationale: This allows broadcast alarm sound levels to exceed the 85 dBA hazard limit because of the need for alarm audibility. Also, alarms can be silenced at the crew's discretion. This requirement does not apply during launch, entry, and abort (see [V2 6074] Ceiling Limit for Launch and Entry and [V2 6075] Ceiling Limit for Launch Abort), as these alarms will be provided by personal audio devices (see [V2 6106] Noise Limit for Personal Audio Devices).]

6.6.1.11 Annoyance Noise Limits for Crew Sleep

[V2 6082] With the exception of communications and alarms, the system **shall** limit impulse and intermittent noise levels at the crewmember's head location to 10 dB above background noise levels during crew sleep periods. Hearing protection cannot be used to satisfy this requirement.

[Rationale: Impulse and intermittent noise is to be limited to 10 dB or less above the background noise to avoid waking crewmembers who are sleeping. Communications and alarms are not subject to this requirement.]

6.6.1.12 Impulse Noise Limit

[V2 6083] The system **shall** limit impulse noise measured at the crewmember's head location to less than 140 dB peak SPL during all mission phases except launch, entry, and abort. Hearing protection cannot be used to satisfy this requirement.

[Rationale: A limit of 140-dB peak SPL for impulse noise prevents acoustic trauma (OSHA 29 CFR 1910.95, Para 1910.95(b)(2) and WHO Environmental Health Criteria 12 – NOISE, Para 3.1.3). Launch, Entry and Abort phases are exempted here as they allow for the use of hearing protection to satisfy a similar impulse noise limit requirement (see [V2 6076] Launch, Entry, and Abort Impulse Noise Limits).]

6.6.1.13 Narrow-Band Noise Limits

[V2 6084] The maximum SPL of narrow-band noise components and tones **shall** be limited to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone.

[Rationale: Narrow-band noise component and tone levels are limited to 10 dB below the broadband level to prevent irritating and distracting noise conditions which could affect crew performance.]

6.6.1.14 Infrasonic Sound Pressure Limits

[V2 6085] Infrasonic SPLs, including frequencies from 1 to 20 Hz but not including impulse noise, **shall** be limited to less than 150 dB at the crewmember's head location. Hearing protection cannot be used to satisfy this requirement.

[Rationale: The 150 dB limit for infrasonic noise levels in the frequency range from 1 to 20 Hz provides for health and well-being effects. Refer to ACGIH, Threshold Limit Values (TLVs®), Infrasound and Low-Frequency Sound, 2001.]

6.6.1.15 Noise Limit for Personal Audio Devices

[V2 6106] The system **shall** limit the maximum A-weighted sound level at the crewmember's ear created by a personal audio device to 115 dBA or less when converted to a diffuse field.

[Rationale: Noise levels above 115 dBA have been shown to produce noise-induced hearing loss. Sound levels produced by personal audio devices are allowed to be at high levels to overcome the noise generated during launch and descent. A personal audio device may be an integrated part of the EVA helmet or an independent communication or listening headset but does not include cabin or broadcast speakers. OSHA identifies 115 dBA as the allowable ceiling for noise exposure limits. This ceiling limit is allowed as long as it does not result in the overall daily TWA exposure exceeding the limit of 85 dBA per requirement [V2 6073] Launch, Entry, and Abort Noise Exposure Limits. Testing is to be conducted to evaluate the upper limits of personal audio devices across all operable 1/3 O.B. frequencies using a swept sine signal driving the transducer acoustic output at the maximum specified device audio input level and the maximum audio output volume setting. Personal audio devices are to be determined compliant if the overall A-weighted levels are no greater than 115 dBA when converted to a diffuse field. This requirement is intended to be measured using an IEC 60318-4 compliant acoustic test fixture or head and torso simulator and converted to a diffuse field per IEEE Std 1652-2016.]

6.6.2 Acoustic and Noise Monitoring

6.6.2.1 Acoustic Monitoring

[V2 6087] Broadband and frequency-dependent SPLs **shall** be monitored and quantified as needed for crew health and safety.

[Rationale: Acoustic monitoring is needed to ensure that sound levels during the mission are below established limits for crew health and performance. As an example, periodically on ISS, the crew uses acoustic monitors to monitor their environment.]

6.6.2.2 Individual Noise Exposure Monitoring

[V2 6088] Noise exposure levels **shall** be monitored and quantified for each crewmember as needed for crew health and safety.

[Rationale: To protect the crew from excessive noise exposure, the noise exposure experienced by the crew is to be understood. This is critical to the protection of crew hearing and helps determine the degree of remedial actions needed, if any, including moving to a different environment, hardware shutdown, or proper implementation of countermeasures. As an example, periodically on ISS, the crew uses acoustic monitors to monitor their environment.]

6.7 Vibration

Limiting crew exposure to vibration is important for mission success. Excessive whole-body vibration can cause injury, fatigue, discomfort, and vision degradation, whereas the primary risk resulting from hand vibration is reduced fine motor control.

6.7.1 Whole Body Vibration

6.7.1.1 Vibration during Preflight

[V2 6089] The system **shall** limit vibration to the crew such that the frequency-weighted acceleration between 0.1 to 0.5 Hz in each of the X, Y, and Z axes is less than 0.05 g (0.5 m/s^2) root mean square (RMS) for each 10-minute interval during prelaunch (when calculated in accordance with ISO 2631-1:1997(E), Mechanical Vibration and Shock - Evaluation of Human Exposure to Whole-Body Vibration - Part 1: General Requirements, Annex D, Equation D-1).

[Rationale: Low-frequency vibration, especially in the range between 0.1 and 0.5 Hz, has the potential to cause motion sickness over relatively short exposure periods. This may be encountered while the crew is in the vehicle during the prelaunch period, given that a tall vehicle stack may be susceptible to back-and-forth sway. Reducing the amount of sway will prevent the onset of motion sickness during the prelaunch phase. According to ISO 2631-1: 1997(E), Annex D, the percentage of unadapted adults who may vomit is equal to 1/3 motion sickness dose value. The value 0.05 g weighted RMS acceleration indicates that approximately 14% or one out of seven crewmembers may vomit. Although ISO 2631-1:1997(E) limits the acceleration measurement for assessing motion sickness to the vertical direction, this is based on the assumption that the human is in the seated upright posture. Since occupants of a vehicle are likely to be in the semi-supine posture, the requirement is applied to all three orthogonal axes (X, Y, and Z). The purpose of the 10-minute integration time is to constrain the deviations around the permitted average sway during a 2-hour prelaunch period.]

6.7.1.2 Vibration Exposures during Dynamic Phases of Flight

[V2 6090] The system **shall** limit vibration during dynamic phases of flight at interfaces that transmit vibration to the crew such that the vectorial sum of the X, Y, and Z accelerations between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), is less than or equal to the levels for the accumulated durations in Table 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight, and Figure 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight.

[Rationale: Although there are limited data on the effects of high levels of vibration on health, especially during concurrent hypergravity acceleration, i.e., >1-g bias, internal organs and tissue structures may be damaged if the vibration amplitude goes over these time durations. This duration (under 10 minutes) is expected to bracket the vibration period during ascent and return. If the dynamic event exceeds this 10-minute duration, requirement [V2 6091] Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission must be used from the 10-minute point onward.

In accordance with ISO 2631-1, Section 6.3.1, vibration calculations are based on a running 1-second time window. The limits depicted in Table 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight, and Figure 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight are to be applied as follows:

1) The calculated frequency-weighted acceleration is to never exceed 6 m/s^2 RMS (0.6 g RMS) for any 1-second time window.

2) The calculated frequency-weighted acceleration may exceed 4 m/s^2 RMS (0.4 g RMS) for no more than 60 non-overlapping 1-second time windows. These 1-second windows may be contiguous or noncontiguous.

3) The calculated frequency-weighted acceleration for all of the remaining 1-second time windows during the maximum 10-minute per day dynamic phases of flight period is not to exceed 4 m/s^2 RMS (0.4 g RMS). These 1-second windows may be contiguous or noncontiguous.]

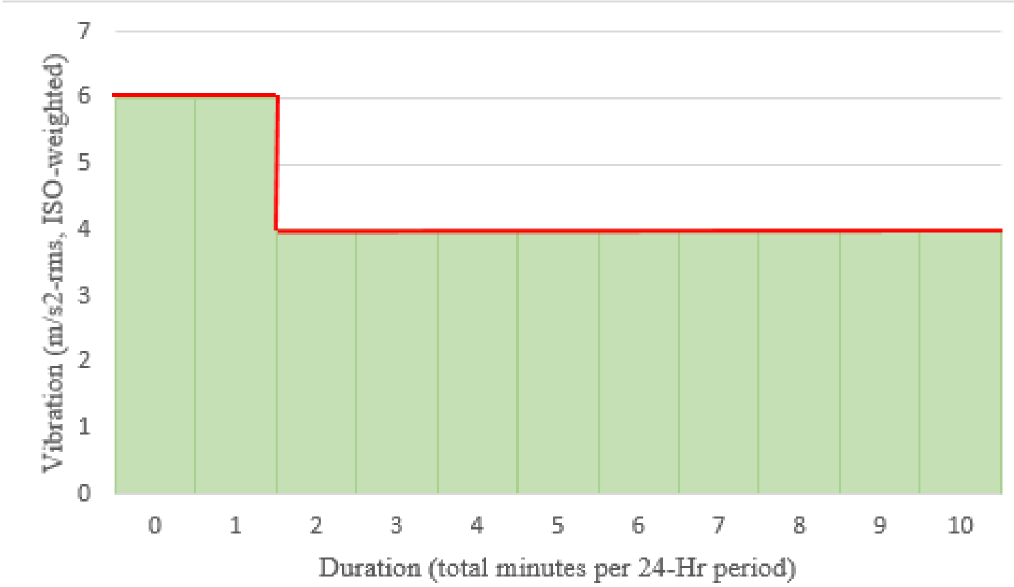


Figure 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight

Table 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight

Maximum Vibration Exposure Duration per 24-hr Period	Maximum Frequency-Weighted Acceleration
10 min	4 m/s^2 RMS (0.4 g RMS)
1 min	6 m/s^2 RMS (0.6 g RMS)

6.7.1.3 Long-Duration Vibration Dosage Limits for Health during Non-Sleep Phases of Mission

[V2 6091] The system **shall** limit vibration at interfaces that transmit vibration to the crew such that the accumulated dosage of the vectorial sum of the X, Y, and Z frequency-weighted accelerations, as computed according to ISO 2631-1:1997(E), does not exceed the minimum health guidance caution zone level defined in Figure 6.7-2—Long-Duration Vibration Dosage Limits for Health during Non-Sleep Phases of Mission.

[Rationale: Biodynamic and epidemiological research provides evidence of elevated health risk related to long-term exposure to high-intensity whole-body vibration. According to ISO 2631-1:1997(E) Annex B.3.1, "[f]or exposures below the [health guidance caution] zone, health effects have not been clearly documented and/or objectively observed."

In accordance with ISO 2631-1:1997(E), Section 6.3.1, vibration calculations shall be based on a running 1-second time window.

For this standard, the equivalent vibration dosage, $a_{w,e}$, is computed per ISO 2631-1:1997(E), Eq. B.4 as:

$$a_{w,e} = \left[\frac{\sum a_{wi}^4 T_i}{\sum T_i}\right]^{1/4}$$

for accumulated exposures up to or equal to 6 hours. For exposures exceeding 6 hours up to 24 hours, $a_{w,e}$, is computed according to ISO 2631-1:1997(E), Eq. B.3 as:

$$a_{w,e} = \left[\frac{\sum a_{wi}^2 T_i}{\sum T_i}\right]^{1/2}$$

where a_{wi} is frequency-weighted acceleration in m/s^2 and T_i is the duration in seconds for the i-th time increment of the overall measurement or analysis period.

The allowable vibration dosage is depicted as a function of accumulated daily exposure time in Figure 6.7-2—Long-Duration Vibration Dosage Limits for Health during Non-Sleep Phases of Mission. A vibration dosage of 3 m/s^2 is permissible for up to 17 seconds of exposure during any 24-hour interval. For exposure durations between 17 seconds and 6 hours, the allowable zone is bounded per ISO 2631-1:1997(E), Eq. B.5, by:

$$1.4 a_w T^{1/4} = 8.5$$

where aw is the bounding vibration dosage accumulated as a function of exposure time, T (in seconds). For exposure durations between 6 and 24 hours, the zone is bounded by ISO 2631-1:1997(E), Eq. B.1:

$$a_w T^{1/2} = a_{w24} T_{24}^{1/2}$$

where the bounding vibration dosage, a_w24 = 0.25 m/s^2 , occurs at T_24 = 795,600 seconds (i.e., 24 hours). Finally, the frequency-weighted acceleration during any single 1-second window is not to exceed 3 m/s^2.]

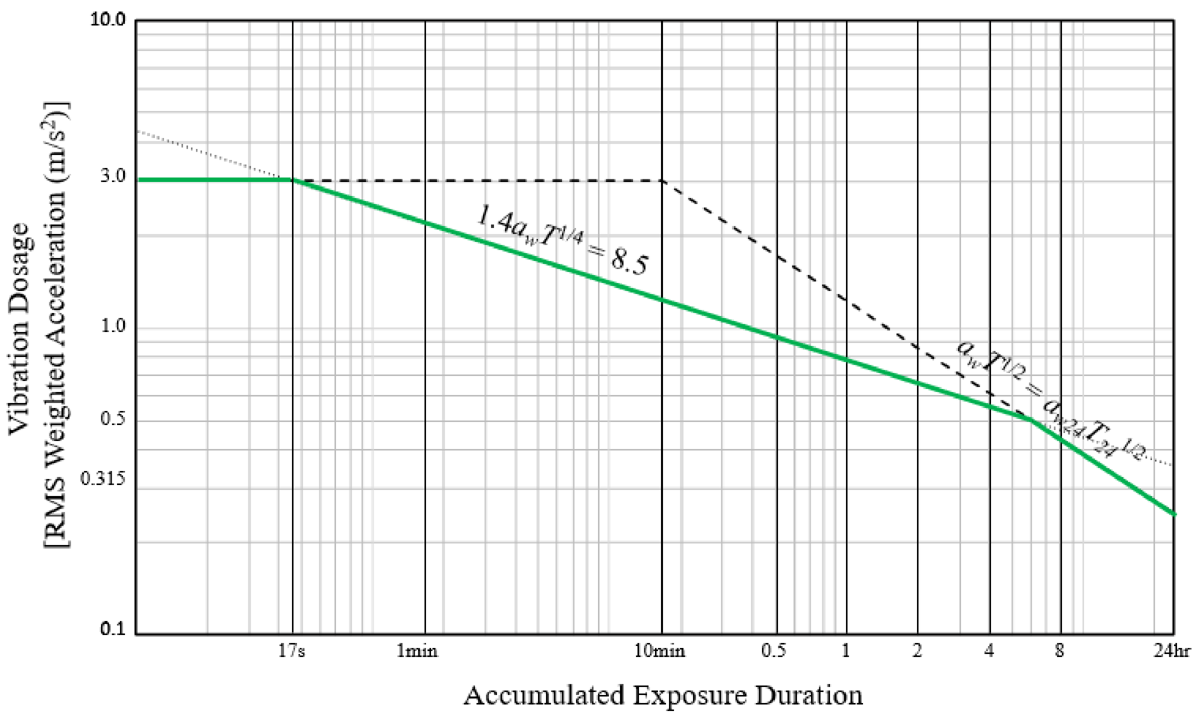


Figure 6.7-2—Long-Duration Vibration Dosage Limits for Health during Non-Sleep Phases of Mission

6.7.1.4 Vibration Exposure Limits during Sleep

[V2 6092] The system **shall** limit vibration to the crew such that the acceleration between 1.0 and 80 Hz in each of the X, Y, and Z axes, weighted in accordance with ISO 20283-5, Mechanical Vibration—Measurement of Vibration on Ships; Part 5 - Guidelines for the Measurement, Evaluation and Reporting of Vibration with Regard to Habitability on Passenger and Merchant Ships, Annex A, is less than 0.01 g (0.1 m/s^2) RMS for each two-minute interval during the crew sleep period.

[Rationale: For long-duration (approximately eight hours), smaller vibration exposure can adversely affect crew sleep. When addressing the vibration limits during sleep, consideration should be given to crewmember contact points (if any) with the system and whether system vibration can be transmitted at these points to the crewmember's body.]

6.7.1.5 Vibration Limits for Performance

[V2 6093] The system **shall** ensure the appropriate level of crew task performance (e.g., motor control accuracy and precision, vision/readability, speech clarity, attentional focus) during vibration by evaluating task performance under all expected (nominal and off-nominal) vibration levels.

[Rationale: It is critical to ensure that the crew can perform mission tasks in the environment to which they will be exposed. For example, ascent and landing are typically accompanied by periods of significant vibration that can affect the crewmembers' motor control and visual performance. Off-nominal conditions such as an aborted launch will expose crewmembers to challenging vibration levels that will limit their ability to perform functions such as reading display panels, turning knobs, activating switches, using touch screens and/or utilizing joystick controllers. Furthermore, by limiting exposure during crew task performance such that the acceleration in each of the frequencies between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), Section 8.2.2.1, below 0.5 m/s^2 (MIL-STD-1472H 2020), one is likely to preserve appropriate performance. At this vibration level, conditions become "fairly uncomfortable" which can be expected to adversely impact performance. Furthermore, this level is consistent with NASA test data and visual performance-based requirement developed for NASA's Orion crew vehicle. Thus, HITL testing with vibration becomes especially imperative for those situations where the 0.5 m/s2 level is anticipated to be exceeded.]

6.7.2 Hand Vibration

[V2 6094] The system, including tools, equipment, and processes, **shall** limit vibration to the crewmembers' hands such that the accelerations, as computed according to ANSI/ASA S2.70-2006, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand, do not exceed the Daily Exposure Action Value defined by ANSI/ASA S2.70-2006, Annex A, Figure A.1.

[Rationale: In accordance with ANSI/ASA S2.70-2006, Annex A.1.1, the Daily Exposure Action Value delineates the health risk threshold defined as "the dose of hand-transmitted vibration exposure sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in some exposed individuals".]

6.7.3 Extraterrestrial Surface Transport Vehicle Vibration Limits for Health and Performance

[V2 6160] The extraterrestrial surface transport vehicle (ESTV) system **shall** limit crewmember exposure to vibration such that the vectorial sum of the X, Y, and Z accelerations between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), is less than or equal to the levels given in Figure 6.7-3—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants) and Table 6.7-2—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants), which specify the allowable accumulated duration (per 24-hour day) of vibration for both standing or seated crewmembers in all restraint conditions.

[Rationale: When addressing the sustained vibration limits, several considerations and general assumptions have been made. Further information can be found in NASA/TM-20220011974 Lunar Transport Vehicle Occupant Protection Requirements. These limits in Table 6.7-2—

Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants) assume no intra-suit restraints other than a standard harness as seen in previous iterations of the EMU-style suit configurations. Additional occupant restraints in the form of inserts and suit modifications were not considered.

To define zones A, B, and C in Table 6.7-2, guidance from ISO 2631-1, MIL-STD-1472H, and MIL-STD-1472G, are leveraged. These documents outline specific health, performance and comfort thresholds based on cumulative exposure duration over a 24hr window. Overlaying the guidance from ISO 2631-1 and MIL-STD-1472 yields a plot with associated health and performance risk likelihoods and comfort levels (Figure 6.7-3—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants).

Guidance from ISO 2631-1 is used to identify the health and performance consideration zone for short duration exposures ($1s \leq t \leq 17s$). For longer exposures ($t > 17s$), comfort guidance from MIL-STD-1472G and H is used. The identified time durations are cumulative dosage per 24hr window.

The ISO 2631-1 weighting function, W_d, and multiplying factor, $k = 1.4$, shall be used for the body x and y axes. The ISO 2631-1 weighting function, W_k, and multiplying factor, $k = 1$, shall be used for the body z axis. Vibration in multiple axes at a given measurement (or analysis) location shall be combined by taking the root sum of squares (RSS) of the weighted vibration in each body axis. If vibration couples to the vehicle occupant's body at multiple locations, the weighted vibration computed as described shall be calculated by taking the RSS across all these locations. Following ISO 2631-1, a 1-s computation window is recommended for processing when all vibration frequency content of interest is at or above 1 Hz; a 2-s window may be used if there is significant frequency content between 0.5 and 1 Hz.

The limits depicted in Table 6.7-2— Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants), and Figure 6.7-3— Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants) are to be applied as follows:

1) *The calculated frequency-weighted acceleration shall never exceed 3 m/s^2 RMS for any 1-second time window.*

2) *The calculated frequency-weighted acceleration may exceed 0.5 m/s^2 RMS for no more than 17 non-overlapping 1-second time windows. These 1-second windows may be contiguous or noncontiguous.*

3) *The calculated frequency-weighted acceleration may exceed 0.315 m/s^2 RMS for up to 216,000 non-overlapping 1-second windows (i.e., 6 hours). These 1-second windows may be contiguous or noncontiguous.*

4) *The calculated frequency-weighted acceleration is not to exceed 0.315 m/s^2 RMS for all remaining 1-second time windows during the 24-hour period. These 1-second windows may be contiguous or noncontiguous.*

It is assumed that the vehicle will provide proper foot restraints and back support in the proposed design. The vehicle occupant is also assumed to always remain in contact with supporting surfaces.

These limits cover all vibrations imposed on the crewmember both directly by the ESTV as well as indirectly by the ESTV through the suit.

Design solutions are expected to contain energy attenuation to mitigate the vibration the crewmember is subjected to.]

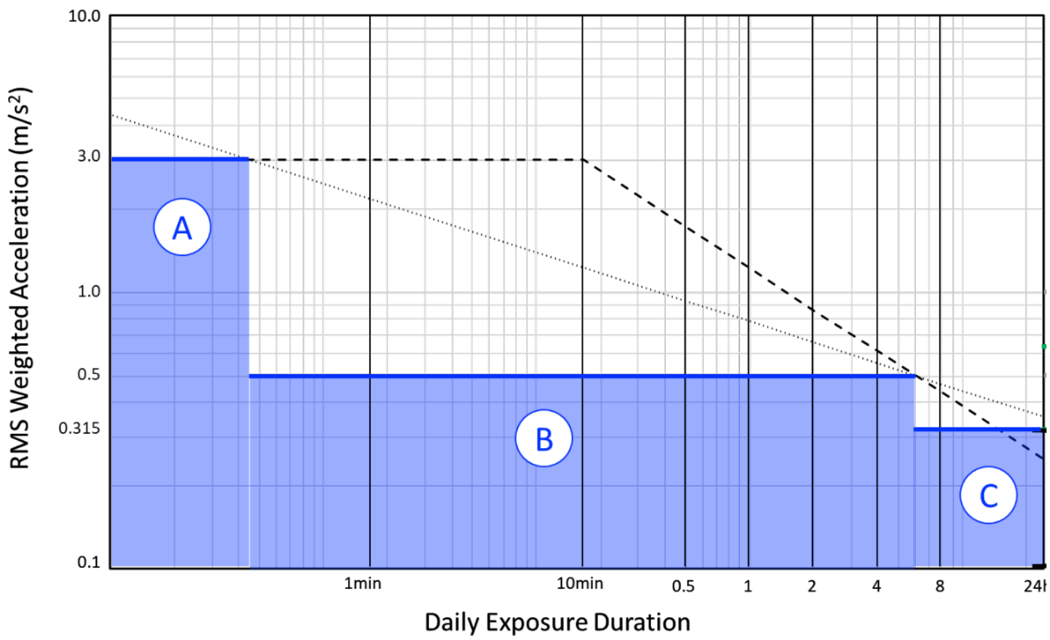


Figure 6.7-3—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants)

Table 6.7-2—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants)

Zone	**A**	**B**	**C**
Source	**ISO 2631-1**	**MIL-STD-1472H**	**MIL-STD-1472G**
Acceleration Limit (ISO-weighted RMS)	3.0 m/s^2	0.5 m/s^2	0.315 m/s^2
Allowable accumulated duration, *t* (dosage per 24-hr interval)	1s ≤ *t* ≤ 17s	17s < *t* < 6hr	6hr < *t* ≤ 24hr

6.8 Radiation

6.8.1 Ionizing Radiation

Exploration of space requires traversal of environments that risk crew exposure to ionizing radiation such as charged particles, neutrons, X-rays and γ-rays. The ionizing radiation present in the mission envelope must be specified to aid in the evaluation and management of the exposure risk. The hazards from occupational exposure to ionizing radiation are mitigated through the application of the As Low As Reasonably Achievable (ALARA) principle during mission planning and vehicle design while the overall risk is limited by adherence to the permissible exposure limits (PELs). Application of the ALARA principle and adherence to PELs specified in Section 4.8 of NASA-STD-3001, Volume 1 protect the crew from acute effects and career-related cancer induced by radiation exposure. No level of increased exposure to ionizing radiation is considered safe and therefore the PELs are exclusion limits rather than tolerance values.

6.8.1.1 Radiation Environments

[V2 6098] The program **shall** specify the radiation environments to be used for design requirements and verification.

[Rationale: Defining the ionizing radiation environments across mission phases provides a starting point for planning and design that adheres to the ionizing radiation requirements set in Section 4.8 of NASA-STD-3001, Volume 1. The specified ionizing radiation environments drive derivative program requirements such as systems design and mission architecture. Definitions of radiation environments include, but are not limited to, specification of solar activity, types of ionizing radiation, energy spectra, and models used to generate the definitions. Example definitions of radiation environments can be found in Section 4.8 of NASA-STD-3001, Volume 1 and throughout SLS-SPEC-159 Cross Program Design Specification for Natural Environments (DSNE).]

6.8.1.2 Ionizing Radiation Protection Limit

[V2 6095] The program **shall** set system design requirements and operational constraints to prevent crewmembers from exceeding career space permissible exposure limits (PELs) as set forth in Section 4.8 of NASA-STD-3001, Volume 1.

[Rationale: Protection limits ensure that missions do no subject crew to ionizing radiation exposure beyond the PELs set in Section 4.8 of NASA-STD-3001, Volume 1. This requirement is imposed to limit the risk of long-term health effects of cancer.]

6.8.1.3 Intravehicular Area Monitoring of Space Radiation Exposure

[V2 6161] The program **shall** monitor the radiation exposure produced by galactic cosmic rays, solar energetic particles, trapped radiation, and neutrons in habitable volumes as referenced in

Table 6.8-1—Space Radiation Monitoring Requirements Mission Location vs. Required Monitoring.

[Rationale: To characterize and manage crew exposure to ionizing radiation while ensuring the PELs are not exceeded, the ionizing radiation in habitable environments must be monitored throughout the course of a mission. Appropriate dose monitoring provides data on the radiation type, linear energy transfer (LET), intensity, and angles of incidence. Timepix-based instruments have been used by past programs to characterize the ionizing radiation inside crewed vehicles and to measure the dose and dose rates.]

Table 6.8-1—Space Radiation Monitoring Requirements
Mission Location vs. Required Monitoring

<table>
<tr><th></th><th></th><th colspan="2">LEO</th><th colspan="2">BLEO</th><th colspan="2">Extraterrestrial Surface</th></tr>
<tr><th></th><th></th><th>Area Monitoring Vehicle/ Habitat</th><th>Personal Monitoring IVA-EVA</th><th>Area Monitoring Vehicle/ Habitat</th><th>Personal Monitoring IVA-EVA</th><th>Area Monitoring Vehicle/ Habitat</th><th>Personal Monitoring IVA-EVA</th></tr>
<tr><td rowspan="3">Charged Particles*</td><td>SPE – solar particle event</td><td colspan="2" rowspan="3">For mission exposures projected to be less than 50 mSv**
Can be assessed via analysis**
Or
Area and/or personal monitors with vehicle analysis can be utilized for IVA and EVA.

For exposures projected to be greater than 50 mSv**
Area and/or personal monitors with vehicle analysis can be utilized for IVA and EVA.*</td><td>Required</td><td>Required</td><td>Required</td><td>Required</td></tr>
<tr><td>GCR - galactic cosmic rays</td><td>Required</td><td>Required</td><td>Required – environment analysis may be substituted</td><td>Required – environment analysis may be substituted</td></tr>
<tr><td>Trapped Particles</td><td>Required</td><td>Required</td><td>N/A</td><td>N/A</td></tr>
<tr><td></td><td>Neutrons</td><td>N/A</td><td>N/A</td><td>Required – environment analysis may be substituted</td><td>Required – environment analysis may be substituted</td><td>Required – environment analysis may be substituted</td><td>Required – environment analysis may be substituted</td></tr>
<tr><td colspan="8">*May be monitored with a single device
** Utilizing the quality factors that are utilized to calculate the NASA effective dose space PEL (refer to Volume 1, Section 4.8)

For exposures greater than 50 mSv the uncertainty of the analysis affects the ability to accurately communicate the risk to the crew member. Crewmembers with multiple missions that exceed 75 mSv of total dose will need additional assessment (actual monitoring vs. analytical assessment) to ensure adequate communication of risk.</td></tr>
</table>

6.8.1.4 Personal Monitoring of Space Radiation Exposure

[V2 6162] The program **shall** monitor the radiation exposure produced by galactic cosmic rays, solar energetic particles, and trapped radiation received by individual crew members as referenced in Table 6.8-1—Space Radiation Monitoring Requirements Mission Location vs. Required Monitoring.

[Rationale: Past and future career exposure to ionizing radiation of individual crew is considered during crew selection and mission planning. To ensure crew do not exceed PELs, the space radiation exposure of each crew member must be monitored on an individual basis as crew activity leads to varying absorbed dose. Individual dose monitoring must occur inside vehicles, habitats, and during extravehicular activity. These devices need to be compact and require minimal crew intervention for dose measurement to ensure crew compliance. The dose measurements from instruments fulfilling this requirement are entered into the crew medical records which are considered during crew selection.]

6.8.1.5 Area Monitoring of Radiation Exposure from Nuclear Technologies

[V2 6163] The program **shall** monitor the crew ionizing radiation exposure from nuclear technologies.

[Rationale: Nuclear technology integration into crewed vehicles and habitats poses an additional radiation exposure hazard beyond that of the space radiation environments. Ionizing radiation produced by nuclear technologies such as fission reactors and radioisotope thermoelectric generators must be monitored to ensure that the subcomponent of crew radiation exposure contributed by nuclear technologies does not exceed the limit set in [V1 4032] Crew Radiation Limits for Nuclear Technologies of NASA-STD-3001, Volume 1. This requirement may be fulfilled by dedicated monitors or instruments for intravehicular and extravehicular monitoring.]

6.8.1.6 Alerting of Elevated Exposure Rates

[V2 6164] The radiation monitoring system **shall** alert the crew and operations teams when radiation exposure rates exceed predefined thresholds.

[Rationale: The crew must be able to follow sheltering procedures planned in the event that dose rates exceed predefined thresholds. The crew must be alerted even if ground communication is disrupted or is unviable. Space weather events have the potential to expose crew to ionizing radiation that exceeds PELs during an event or through cumulative exposure over the course of a mission. Nominal communication mechanisms can be affected during space weather events requiring the monitoring systems to autonomously alert the crew or generate a signal to alarm through a connected system. The systems must alert operations teams if communication is available or upon being restored.]

6.8.1.7 External Space Weather Monitoring

[V2 6165] The program **shall** monitor the in-situ extravehicular space weather environment including the external exposure rates, electron flux spectra, and proton flux spectra.

[Rationale: Space weather events alter the typical mission radiation environments in ways that risk crew exposure to large doses of ionizing radiation before crew have adequate time to shelter. External radiation monitors can provide early warning to crew and ground personnel by

detecting precursor particles that arrive ahead of the ionizing radiation that carries the bulk of exposure-related hazard. Space weather monitors that meet this requirement differ from crew dose monitors by their sensitivity to radiation typically absorbed by the shielding afforded by the vehicle or habitat. Space weather monitors must avoid saturation during significant storming such that exposure rates during such storms could be estimated. Historically significant space weather storming includes the August 1972 and October 1989 events.]

6.8.2 Non-Ionizing Radiation

Sources of non-ionizing radiation are present in spaceflight applications, and exposure is potentially hazardous. Astronaut occupational exposure to non-ionizing radiation is managed through mission architecture, system design, procedures and planning, and application of appropriate countermeasures. This NASA Technical Standard classifies non-ionizing radiation into four categories: radio frequency (RF) electromagnetic radiation, lasers, natural incoherent light, and artificial incoherent light.

6.8.2.1 RF Non-Ionizing Radiation Exposure Limits

[V2 6102] The system **shall** maintain the crew exposure to RF electromagnetic fields to or below the limits stated in Table 6.8-2—Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields and shown graphically in Figure 6.8-1—RF Electromagnetic Field Exposure Limits.

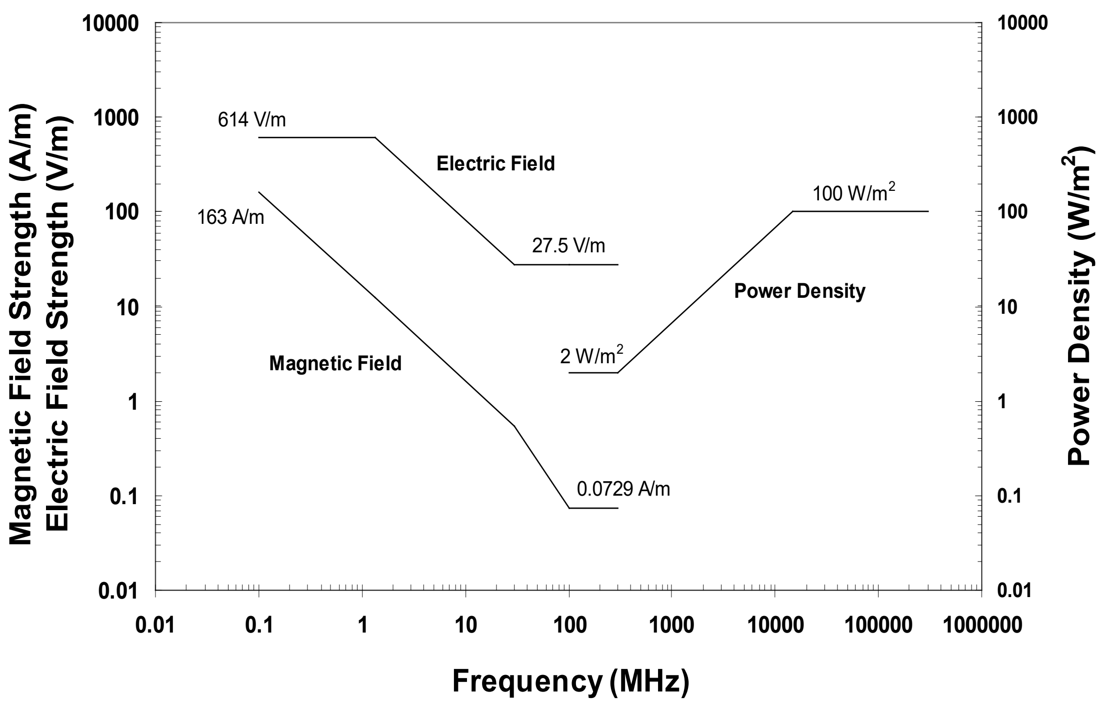
[Rationale: Examples of devices that generate radio frequency radiation include, but are not limited to, antennas and wireless systems. These limits are modified from the C95.1-2005, Institute of Electrical and Electronic Engineers (IEEE). They are intended to establish exposure conditions for radio-frequency and microwave radiation to which it is believed that nearly all workers can be repeatedly exposed without injury. Modifications were made to the C95.1-2005 power density values to remove a safety margin that was added in the C95.1 standard to include the children population. This is not applicable to astronaut corp and resulted in the relaxation of the C95.1-2005 limits as per Figure 5.7.3.2.1-1, Occupational Exposure Limits for Radio-Frequency Electromagnetic Fields.]

Table 6.8-2—Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields (modified from IEEE C95.1-2005, lower tier)

Frequency Range (MHz)	RMS Electric Field Strength (E)[a] (V/m)	RMS Magnetic Field Strength (H)[a] (A/m)	RMS Power Density (S) E–Field, H–Field (W/m^2)	Averaging Time[b] $\lvert E\rvert^2$, $\lvert H\rvert^2$, or S (min)	
0.1 – 1.34	614	$16.3/f_M$	$(1{,}000,\ 100{,}000/f_M^2)$ [c]	6	6
1.34 – 3	$823.8/f_M$	$16.3/f_M$	$(1{,}800/f_M^2,\ 100{,}000/f_M^2)$	$f_M^2/0.3$	6
3 – 30	$823.8/f_M$	$16.3/f_M$	$(1{,}800/f_M^2,\ 100{,}000/f_M^2)$	30	6
30 – 100	27.5	$158.3/f_M^{1.668}$	$(2,\ 9{,}400{,}000/f_M^{3.336})$	30	$0.0636 f_M^{1.337}$
100 – 300	27.5	0.0729	2	30	30
300 - 5000	–	–	$f/150$	30	

Frequency Range (MHz)	RMS Electric Field Strength (E)[a] (V/m)	RMS Magnetic Field Strength (H)[a] (A/m)	RMS Power Density (S) E–Field, H–Field (W/m^2)	Averaging Time[b] $\|E\|^2$, $\|H\|^2$, or S (min)
5000 - 15000	–	–	$f/150$	$150/f_G$
15000 – 30,000	–	–	100	$150/f_G$
30,000 – 100,000	–	–	100	$25.24/f_G^{0.476}$
100,000 – 300,000	–	–	100	$5048/[(9f_G\text{-}700)f_G^{0.476}]$

Note: f_M is the frequency in MHz; f_G is the frequency in GHz.
(a) For exposures that are uniform over the dimensions of the body such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area) or a smaller area, depending on the frequency, are compared with the MPEs in the table. For further details, see IEEE C95.1-2005, notes to Table 8 and Table 9.
(b) The left column is the averaging time for $|E|^2$; the right column is the averaging time for $|H|^2$. For frequencies greater than 400 MHz, the averaging time is for power density (S).
(c) These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.



(Illustrated to show whole-body resonance effects around 100 MHz) (modified from IEEE C95.1-2005, lower tier)

Figure 6.8-1—RF Electromagnetic Field Exposure Limits

6.8.2.2 Laser Exposure Limits

[V2 6103] The system **shall** maintain the crew ocular and dermal exposure to laser systems and the ocular exposure of the uncontrolled ground population to space lasers to or below the limits specified in ANSI Z136.1, 2014, American National Standard for Safe Use of Lasers, Table 5 (ocular) and Table 7 (dermal) without Personal Protective Equipment.

[Rationale: This requirement limits crew ocular and dermal exposure to both continuous and repetitively pulsed lasers to protect against eye and skin injury. The limits are adopted from the Laser Institute of America's (LIA) publication ANSI Z136.1, 2014. The term laser system includes the laser, its housing, and controls. This requirement applies to laser systems utilized both internal and external to the vehicle. The safety analysis of all lasers will be carried out by ANSI Z136.1 methodology as specified in the verification requirement. In addition, this requirement limits uncontrolled ground population ocular exposure to space lasers. The limits are adopted from ANSI Z136.1, 2014. ANSI Z136.6, 2015, which may be used for guidance on laser hazard analysis methodology.]

6.8.2.3 Natural Sunlight Exposure Limits

[V2 6104] The system **shall** maintain the crew exposure to natural sunlight for spectral radiance or irradiance (as applicable) within wavelengths between 180 nm and 3000 nm, as noted in Table 6.8-3—Natural Sunlight Exposure Limits for Different Damage Mechanisms.

[Rationale: This requirement is intended to prevent ocular and dermal injury from sunlight exposure with wavelengths between 180 and 3000 nm. Any exposure should consider the entire window configuration of the incident radiation prior to its interaction with a crewmember's body, including any concentration, diffusion, or filtering. The transmittance required for windows, visors, and other optical devices can be reconciled with protection from natural sunlight through the use of protective personal equipment, temporary filters, proper material selection, apertures, or other appropriate means. The sun subtends an angle of approximately 9 milliradians when observed from the Earth and is, therefore, considered a small source. The limits are based on the methodology given in the 2014 American Conference of Governmental Industrial Hygienists (ACGIH) standard, Threshold Limit Values® (TLVs) and Biological Exposure Indices® (BEIs), sections Light and Near-Infrared Radiation and Ultraviolet Radiation (2014 or newer). This requirement is applicable to both hatch and module windows.]

Table 6.8-3—Natural Sunlight Exposure Limits for Different Damage Mechanisms

Requirement	ACGIH 2014 – TLVs Equations in the Optical Radiation Section	Units	Pass Criteria	Damage Mechanism
Visible and Near-Infrared Radiation 380-3000 nm (relaxed 2x)	Equations 4a, 4b (Section 1)*	Seconds (Eq. 4a) Factors over allowable irradiance (Eq. 4b)	$T_{max} \geq 0.25$s (Eq. 4a) Weighted irradiance divided by TLV ratio ≤1 (Eq. 4b)	Retinal Thermal
Visible Radiation 305-700 nm (relaxed 5x)	Equation 8b (Small Source) (Section 2)*	Seconds (Eq. 8b)	$T_{max} \geq 0.25$ sec (Eq. 8b)	Retinal Photochemical
Ultraviolet Exposure 180-400 nm (not relaxed)	Equations 3, 4 (Ultraviolet Radiation)*	Minutes (Eq. 3, Eq. 4)	$T_{max} \geq 480$ min (Eq. 3) $T_{max} \geq 17$ min (Eq. 4)	Corneal, Skin

**Injury TLVs from visible light presume a dark-adapted pupil with additional factors of safety applied. A minimum safety factor of 2 in the spectral radiance L_λ source terms has been included in the ACGIH standard. A minimum safety factor of 5 in the spectral irradiance E_λ source terms has been included in the ACGIH standard. To eliminate this excess conservatism, the requirement should relax the spectral radiance L_λ by multiplying it by a factor of 1/2 and the spectral irradiance E_λ by multiplying it by a factor of 1/5. Thus, Equations 4a and 4b are subjected to the 2x relaxation factor, while Equation 8b is subjected to the 5x relaxation factor. This reduction does not apply to ultraviolet radiation. Thus, Equations 3 and 4 are not subjected to any relaxation factors.*

These limits do not apply to laser exposure (see laser exposure limits). Older versions of the ACGIH TLVs should not be utilized due to substantial differences in hazard functions. These limits do not account for forced chronic solar viewing.

NOTE: Refer to ACGIH 2014 for all equations referenced in this table.

6.8.2.4 Artificial Light Exposure Limits

[V2 6117] The system **shall** limit crew exposure from Visible, Infrared (IR), near-IR and Ultraviolet (UV) artificial light sources (180 nm to 3000 nm) at or below the threshold limit value (TLV) as calculated per ACGIH version 2022 or later.

[Rationale: This requirement is intended to prevent ocular and skin injury caused by overexposure to visible, IR, near-IR and UV artificial light sources. Examples of artificial light sources include light-emitting diodes (LEDs), illumination lamps, ambient lightning, display screens, welding and carbon arcs, etc. Indicator LEDs are not subject to this requirement.

Exposure to visible light sources whose luminance does not exceed 10,000 Nits is safe (1 Nit = 1 Candela per meter squared; 1 Nit = 1cd/m^2). Exposure to visible light sources whose luminance exceeds 10,000 Nits and is below 10,000,000 Nits is considered of marginal severity. Therefore, the ACGIH limits for visible light are required only for artificial sources exceeding 10,000,000 Nits as per Table 6.8-4—ACGIH Requirements Applicability. The ACGIH requirement compliance and pass criteria are summarized in Table 6.8-5—ACGIH Requirement Compliance and Pass Criteria. Although not explicitly stated in ACGIH, the assumed viewing distance is 10 cm since this is the minimum focus length of the human eye and thus the largest optical power/hazard potential on to the retina. ACGIH pass criteria for visible light account for the 0.25 seconds human aversion response (i.e., time to look away and/or blink). However, the protection offered by the aversion response will not occur if the light intensity is great enough to *produce damage in less than 0.25 seconds, as explained in the ACGIH. Note: Older than 2014 versions of the ACGIH TLVs cannot be utilized due to substantial differences in hazard functions.*

Full containment and/or applied shielding are acceptable methods of risk reduction; however, need to assume worst case hazard severity (Catastrophic) and corresponding fault-tolerance requirements. Containment examples include the use of light-tight structures and enclosures to fully contain the light at the source. The applied shielding has to be placed between crewmember and the light source; examples include screens, optical filters, etc.]

Table 6.8-4—ACGIH Requirements Applicability

Requirement/ Damage Mechanism	Luminance Value (Nits)	ACGIH Calculations Applicability
Visible Light (380-770 nm) *Retina: Thermal* **Visible Light (305-700 nm)** *Lens, Retina: Photo-chemical*	$<10^4$ Nits Eye safe	N/A
	$<10^7$ Nits Marginal Hazard	N/A
	$\geq 10^7$ Nits Critical or Catastrophic Hazard	ACGIH calculations needed
IR/Near-IR Light (770-3000 nm) *Cornea, Retina: Thermal*	N/A	ACGIH calculations needed
Ultraviolet (180-400 nm) *Cornea, Lens, Retina, Skin*	N/A	Full Containment or ACGIH calculations needed

Table 6.8-5—ACGIH Requirement Compliance and Pass Criteria

Requirement/ Damage Mechanism	Parameter/ Units	ACGIH 2022 Section/Equation	ACGIH 2022 Pass Criteria
Visible Light (380-770 nm) *Retina: Thermal*	Total Effective Radiance $W \cdot cm^{-2} \cdot sr^{-1}$	Section 4 [10, 12b[1,2], 13a[1,2]]	$T_{max} \geq 0.25$ sec If a>0.1 rad: $LR \leq 45\ W \cdot cm^{-2} \cdot sr^{-1}$ If α<0.1 rad: $LR \leq 4.5 \cdot \alpha^{-1}\ W \cdot cm^{-2} \cdot sr^{-1}$
Visible Light (305-700nm) *Lens, Retina: Photo-chemical*	Effective Radiance $W \cdot cm^{-2} \cdot sr^{-1}$	Section 1 [1, 2a[1], 3[2], 4a[1,2]]	$T_{max} \geq 0.25$ sec If α>0.011 rad: $L_B \leq 400\ W \cdot cm^{-2}$ If α<0.011 rad: $E_B \leq 0.04\ W \cdot cm^{-2}$
IR and Near-IR Light (770-3000 nm) *Cornea, Lens: Thermal*	Total Infrared Irradiance $W \cdot cm^{-2}$	*Section 2* [6, 7b]	$E_{IR\text{-}only} \leq 0.01\ W \cdot cm^{-2}$

Requirement/ Damage Mechanism	Parameter/ Units	ACGIH 2022 Section/Equation	ACGIH 2022 Pass Criteria
IR and Near-IR Light (770-3000 nm) *Retina: Thermal*	Total Effective Radiance $W \cdot cm^{-2} \cdot sr^{-1}$	*Section 2, 3* [8, 9b[2]]	$L_{Near\text{-}IR} \leq 0.6 \cdot \alpha^{-1}$ $W \cdot cm^{-2} \cdot sr^{-1}$
Ultraviolet (180-400 nm) *Cornea Lens, Retina: Photochemical*	Effective Radiance over 8 hours $J \cdot m^{-2}$	*Section "UV Radiation"* [1, 2, 4-7]	See ACGIH Table 6.8-1 in this section for all TLVs (delineated per UV wavelength)
Ultraviolet (180-300 nm) *Skin (only)*	Effective Radiance $J \cdot m^{-2}$	*Section "UV Radiation"* [1, 3]	See ACGIH Table 6.8-2 in this section for all TLVs (delineated per UV wavelength)
Note: Refer to ACGIH 2022 for all equations referenced in this table. [1] *Assume a 0.25 second aversion response time or calculate T_{max}.* [2] *Dependent on angular subtense, a. See Equation 11 in Section 4.*			

7. HABITABILITY FUNCTIONS

This section addresses the features of the system required for human occupancy. The specific needs and designs for each feature vary with the type of mission.

7.1 Food and Nutrition

7.1.1 Food Quality and Quantity

7.1.1.1 Food Quality

[V2 7001] The food system **shall** maintain food safety and nutrition during all phases of the mission.

[Rationale: A nutritious, viable, and stable food system that the crew is willing and able to consume is critical for maintaining the health of the crew. The viability of the food system requires not only that food be available for consumption but also that the food has the appropriate nutrient mix to maintain crew health over time. The food is to retain its safety, nutrition, and acceptability for any spaceflight concept of operations, be it of short or long duration.]

7.1.1.2 Food Acceptability

[V2 7002] The system **shall** provide food that is acceptable to the crew for the duration of the mission.

[Rationale: A viable and stable food system that the crew is willing and able to consume is critical for maintaining the health of the crew. The crew's willingness to consume these nutrients is impacted by the variety and flavor of the food. Consideration is given to provide a variety of food frequency, texture, and flavor while maintaining nutritional integrity as these factors can affect crew food acceptance. Additionally, crews originating from different cultural backgrounds and eating habits can influence the development of the food menu options or items supplied.

The dynamics of spaceflight present numerous challenges to food acceptability. A NASA food item measuring an overall acceptability rating of 6.0 or better on a 9-point hedonic scale for the duration of the mission is considered acceptable. The hedonic scale is a quantitative method that is accepted throughout the food science industry as a means to determine acceptability. Further information regarding methods for determining food acceptability can be found in Meilgaard, M., et al. (1999). Food freshness will impact acceptability over time; thus, it is imperative to provide acceptable food initially and a packaging and storage system that will maintain this freshness. Alternatives include growing food or providing basic ingredients and allowing flexibility in their combination and preparation, as well as providing the crew with various condiments to adjust flavors as needed due to the fluid shifts in their sinuses. The ability to customize with some preference foods and with condiments is important to add some variety and *customization, which can help to prevent menu fatigue and support adequate consumption, especially as missions become longer.]*

7.1.1.3 Food Caloric Content

[V2 7003] The system **shall** provide each crewmember with an average of 12,698 kJ (3,035 kcal) per day, else an average energy requirement value is determined using Table 7.1-1—EER Equations and applying an activity factor appropriate to the mission gravity and planned level of physical activity.

[Rationale: The energy intake provisioning will need verification by analysis to determine energy content of each food item and subsequent menu. The minimum number of calories per day is based on the estimated energy requirements (EER) with an activity factor (AF) of 1.25 (active) as calculated according to Table 7.1-1 EER Equations. With this activity factor applied, the average for 84 male crewmembers with an average body mass of 82.9 kg is 12,724 kJ (3,041 kcal). The average for 20 female crewmembers with an average body mass of 65.1 kg is 9,807 kJ (2,344 kcal). This equation is based on National Academy of Medicine's Dietary Reference Intake (DRI). Refer also to document JSC 67378 Nutritional Requirements for Exploration Missions up to 365 days, which notes activity factors ranging from 1.0 to 1.25 based on local gravity and exercise capability.]

Table 7.1-1—EER Equations

Estimated Energy Expenditure
<u>EER for men 19 years old and older</u> EER (kcal/day) = 662 – 9.53 x Age [y] + AF x (15.9 x Body Mass [kg] + 539.6 x Height [m]) <u>EER for women 19 years old and older</u> EER = 354 – 6.91 x Age [y] + AF x (9.36 x Body Mass [kg] + 726 x Height [m])

7.1.1.4 EVA Food Caloric Content

[V2 7004] For crewmembers performing EVA operations, the food system **shall** provide an additional 837 kJ (200 kcal) per EVA hour above nominal metabolic intake as defined by [V2 7003] Food Caloric Content, of this NASA Technical Standard.

[Rationale: Additional energy and nutrients are necessary during EVA operations, as crewmember energy expenditure is greater during those activities. Consumption of an additional 837 kJ (200 kcal), similar in nutrient content to the rest of the diet, per hour of EVA would allow a crewmember to maintain lean body weight during the course of the mission. This is the metabolic energy replacement requirement for moderate to heavy EVA tasks.]

7.1.1.5 Food Nutrient Composition

[V2 7100] The system **shall** provide a food system with a diet including the nutrient composition that is indicated in the Dietary Reference Intake (DRI) values as recommended by the National Institutes of Health, with the exception of those adjusted for spaceflight as noted in Table 7.1-2—Nutrient Guidelines for Spaceflight.

[Rationale: Macronutrients are nutrients that provide calories for energy and include carbohydrates, protein, and fat. Micronutrients are essential elements the body uses in trace amounts and can include vitamins and minerals. These are necessary to maintain the health of the crew. It is recommended that all food and ingredients are sourced from a major chain grocery store or food companies with a quality assurance system in place that audits their suppliers for compliance with federal, state, and local food regulations and laws including but not limited to Food Safety Modernization Act (FSMA), Current Good Manufacturing Practices (CGMP), Hazard Analysis, and Risk-Based Preventive Controls in accordance with the Code of Federal Regulations (CFR) Title 21 and Title 9 as applicable.]

Table 7.1-2—Nutrient Guidelines for Spaceflight

Nutrients	Daily Dietary Intake*
Vitamin D	25 µg (micrograms)

** This field is only expressed in metric units of measure.*

7.1.1.6 Food and Impacts to Environmental Systems

[V2 7110] Food items and packaging **shall** be evaluated for impacts on vehicle systems.

[Rationale: Foods and packaging material are subject to off-gas testing before approval for flight. For example, use of alcohol on the ISS is prohibited due to impacts to the ISS ECLSS. Use of any ingredients containing even small quantities of alcohol, such as ethanol in extracts, vinaigrettes, or cooking wine, require a review to ensure no effects to any environmental control or waste management systems. These items will need to be evaluated as noted in [V2 6023] Trace Constituent Monitoring and Alerting and [V2 6050] Atmosphere Contamination Limit. Liquids or foods containing alcohol also need to be evaluated per NASA-STD-6016 to determine flammability impacts in relation to the atmospheric parameters, especially O_2 saturation. Additionally, food items selected need to consider the impacts to metabolic waste and water recovery system.]

7.1.2 Food Safety

7.1.2.1 Food Safety

[V2 7111] The program **shall** maintain flight food safety throughout product life cycle.

[Rationale: Food safety is important during flight. Unsafe food could cause food poisoning with symptoms including stomach cramping, nausea, vomiting, diarrhea, and dehydration. With

limited medical capability and limited food inventory in spaceflight, it could cause loss of mission objectives. Additional information on pre- and post-launch food service operations, especially how it aligns with the Health Stabilization Program (HSP), can be found in JSC 67627, Pre-Launch and Post-Landing Food Service Operational Procedures.]

7.1.2.2 Food Production Facility

[V2 7112] The facility where food is prepared, processed, packaged, stowed, and stored **shall** comply with applicable laws and regulations, or FDA equivalent, as well as industry Good Manufacturing Practice standards.

[Rationale: This could include limited access to prevent food adulteration. All personnel working directly with food intended for human consumption are expected to receive food handling training equivalent to or exceeding the requirement for obtaining a food handler's permit from the local health authority (i.e., ServSafe® certification, or the equivalent). Appropriate personnel behaviors that can contaminate food, such as properly washing and caring for hands and wearing proper PPE (e.g., disposable lab coat, hair nets, face mask, gloves, and beard nets when applicable) are required when handling exposed food and packaged food for flight at NASA.]

7.1.2.3 Food and Production Area Microorganism Levels

[V2 7007] Microorganism levels in the food and production area **shall not** exceed those specified in Table 7.1-3—Food Microorganism Levels.

[Rationale: To maintain the health and safety of the crew, it is necessary to control microorganism growth. The facility where food is prepared, processed, packaged, stowed, and stored will need to comply with applicable federal/state/local laws and regulations and industry Good Manufacturing Practice standards.]

Table 7.1-3—Food and Production Area Microorganism Levels

Area/Item	Microorganism Tolerances	
Food Production Area	**Samples Collected**	**Limits**
Surfaces	3 surfaces sampled[a]	3000 CFU/ft^2 (total aerobic count)
Packaging Materials	Before use	3000 CFU per Pouch, Septum, 25 cm^2 or base
Air	1 sample of 320 L monthly	113 CFU/320 L (total aerobic count)

Food Product	Factor	Limits
Non-Thermostabilized[b]	Total aerobic count	20,000 CFU/g for any single sample (or if any two samples from a lot exceed 10,000 CFU/g)
	Enterobacteriaceae	100 CFU/g for any single sample (or if any two samples from a lot exceed 10 CFU/g). No detected serious or severe hazard human enteric pathogenic organisms
	Salmonella	0 CFU/g for any single sample
	Yeasts and molds	1000 CFU/g for any single sample (or if any two samples from a lot exceed 100 CFU/g or if any two samples from a lot exceed 10 CFU/g *Aspergillus flavus*)
In-House Thermostabilized Products	Package integrity inspection	100% inspection for package integrity
	Incubation test	Test package must remain intact with no gas production following 10-day incubation at 35 ± 3°C
Commercial Thermostabilized Products	Package integrity inspection	100% inspection for package integrity
Irradiated Sterile Products	Package integrity inspection	100% inspection for package integrity
	Incubation test	Test package must remain intact with no gas production
	Total aerobic count	<10 CFU/g Note: test conducted on samples following incubation at 35° C for 10 days
	Yeasts and molds	<10 CFU/g Note: test conducted on samples following incubation at 35° C for 10 days

Notes:
a. Samples collected only on days that food facility is in operation. Additional environmental samples will be collected when there is a one-hour break in activity, or after five hours of continuous work.
b. Food samples considered "finished" products that do not require additional repackaging are tested only for total aerobic counts.

7.1.2.4 Food Contamination Control

[V2 7010] The food storage, preparation, and consumption areas within the vehicle **shall** be designed and located to protect against cross-contamination between food and the environment.

[Rationale: Contamination can occur from a number of sources within the vehicle due to the closed environment, including proximity to cross-contamination, toxic materials, and the growth of microorganisms. Food is to be processed properly and stored to control or eliminate microbiological concerns. Furthermore, it is critical for crew physical and psychological health that waste management systems (such as food waste, body waste, personal hygiene, exercise) are separate from food preparation, stowage, and consumption activities to protect from cross-contamination. Spaceflight lessons learned indicate this has been an issue during Apollo and ISS missions.]

7.1.2.5 Food System Cleaning and Sanitizing

[V2 7015] The system **shall** provide methods for cleaning and sanitizing food facilities, equipment, and work areas.

[Rationale: The ability to clean and disinfect the food system areas helps to minimize microbial contamination of the food system. Contamination of the food system by physical debris can jeopardize the safety and health of the crew.]

7.1.2.6 Food Spill Control

[V2 7014] The system **shall** provide the ability to contain and remove food particles and spills.

[Rationale: The ability to clean spills or food particles in any area of the vehicle helps to minimize contamination of the spacecraft. Contamination of the food system might occur if spills are not contained, and the physical debris of food particles can jeopardize the safety and health of the crew.]

7.1.3 Food Preparation, Consumption, and Cleanup

7.1.3.1 Food Preparation

[V2 7008] The system **shall** provide the capability for preparation, consumption, and stowage of food.

[Rationale: A viable and stable food system that the crew is willing and able to consume is critical for maintaining the health of the crew. Preparation addresses the heating of the food, if necessary, and the use of required equipment. Consumption relies on utensils or implements such as forks or spoons, a method to open packaging, or a method to rehydrate. Stowage is needed for the food, as well as all the implements for preparation and consumption.]

7.1.3.2 Food Preparation and Cleanup

[V2 7009] The food system **shall** allow the crew to unstow supplies, prepare meals, and clean up for all crewmembers within the allotted meal schedule.

[Rationale: Meal preparation and clean up activity planning takes into account previous spaceflight lessons learned, the water delivery and food heating systems, stowage configuration, and desire of the crew to dine together. This is to help ensure that mission goals, objectives, and timelines are not negatively impacted.]

7.1.3.3 Food and Beverage Heating

[V2 7011] The system **shall** provide the capability to heat food and beverages to a temperature appropriate for the given item.

[Rationale: Heating is necessary for the subjective quality of food. Heating food and liquid enhances the palatability of some items, which is important for psychological health, as well as for ensuring that crewmembers eat the food provided. Maintaining the temperature of rehydrated food helps prevent microbial growth. The vehicle is to provide the ability to heat dehydrated and non-rehydrated foods.]

7.1.3.4 Dining Accommodations

[V2 7012] The system **shall** provide adequate volume and accommodations for crewmembers to dine together.

[Rationale: Dining together has been shown to support the crew's psychological health and well-being. The food system must account for the volume for all the crewmembers to prepare their meal, gather simultaneously, and accommodate any equipment needed to restrain the food and implements, including utensils necessary for dining. The design and layout of the dining space is based on a functional task analysis. The specific volume and layout are to meet the requirements defined in Section 8, Architecture, in this NASA Technical Standard. Additional guidance for design for habitable volume is provided in Chapter 8 of the Human Integration Design Handbook (HIDH).]

7.2 Personal Hygiene

7.2.1 Personal Hygiene Capability

[V2 7016] Personal hygiene items **shall** be provided for each crewmember, along with corresponding system capabilities for oral hygiene, personal grooming, and body cleansing.

[Rationale: Oral hygiene and personal grooming activities are to be accommodated by the system through provision of adequate and comfortable bathing and body waste management facilities as these enhance self-image, improve morale, and increase productivity of the crewmember. Each crewmember is to have personal hygiene provisions, e.g., toothbrush, toothpaste, moistened cloth wipes for body cleansing, deodorant for odor control, oral hygiene, and personal grooming throughout each space mission. Personal hygiene equipment and supplies are to accommodate the physiological differences in male and female crewmembers in microgravity and partial gravity environments. Considerations for crew acceptability should be taken into account as this will impact their overall behavioral performance.]

7.2.2 Body Cleansing Privacy

[V2 7017] The system **shall** provide for privacy during personal hygiene activities.

[Rationale: Certain hygiene functions are to have a degree of privacy, especially in a vehicle in which other crewmembers may be performing other functions simultaneously. Privacy provides

for the psychological well-being of the crew and is to be provided for whole-body and partial-body cleaning and donning and doffing of clothing.]

7.2.3 Hygiene Maintainability

[V2 7019] The system **shall** provide an environmentally compatible sanitization method for personal hygiene facilities and equipment.

[Rationale: To remain hygienic, personal hygiene equipment is to be easily cleaned, sanitized, and maintained. Cleaning and sanitizing helps control odor and microbial growth. As part of the overall maintenance of the hygiene facilities, crewmembers are to have readily accessible trash collection for disposable personal hygiene supplies to minimize crew exposure to the used items.]

7.3 Body Waste Management

7.3.1 Body Waste Management Facilities

7.3.1.1 Body Waste Management Capability

[V2 7020] The system **shall** provide the capability for collection, containment, and disposal of body waste for both males and females.

[Rationale: A body waste management system facilitates the clean, efficient, and reliable collection and management of human waste (urine, feces, vomitus, and menses) and associated equipment and supplies.]

7.3.1.2 Body Waste Management System Location

[V2 7021] The body waste management system **shall** be isolated from the food preparation and consumption areas for aesthetic and hygienic purposes.

[Rationale: Contamination can occur from a number of sources, including proximity to cross-contamination and the growth of microorganisms. It is critical for crew physical and psychological health that any interference between body waste management functions and food preparation and consumption be prevented. The isolation of the body waste management system can be achieved by a physical barrier and/or distance from the food system areas to prevent concerns from cross-contamination. Spaceflight lessons learned indicate this has been an issue during Apollo and ISS missions. For example, due to the close proximity (about 1-foot) of the food system area and body waste management areas, the Apollo crews commented on having diminished appetites. Additionally, complaints from Skylab included the difficulties during defecation due to the awkward placement of the toilet.]

7.3.1.3 Body Waste Management Privacy

[V2 7022] The system **shall** provide privacy during use of the body waste management system.

[Rationale: Certain hygiene functions are to have a degree of privacy, especially in a vehicle in which other crewmembers may be performing other functions simultaneously. Privacy provides for the psychological well-being of the crew and is to be provided for use of the body waste management system.]

7.3.1.4 Body Waste Management Provision

[V2 7023] Body waste management supplies **shall** be provided for each crewmember and be located within reach of crewmembers using the body waste management system.

[Rationale: Personal hygiene and body waste management supplies such as tissues and towels may need to be accessed rapidly.]

7.3.1.5 Body Waste Accommodation

[V2 7024] The body waste management system **shall** allow a crewmember to urinate and defecate simultaneously without completely removing lower clothing.

[Rationale: Accidental discharge of one or both waste components into the habitable volume is not wanted, and it may be difficult for a human to relax the gastrointestinal control sphincter without relaxing the urinary voluntary control sphincter and vice versa. To minimize impact to crew operations, waste elimination needs to be accomplished with minimal crew overhead, e.g., without completely removing clothing.]

7.3.1.6 Body Waste Containment

[V2 7025] The system **shall** prevent the release of body waste from the body waste management system.

[Rationale: A release of waste into the closed environment of a spacecraft can contaminate the human and risk the initiation or spread of disease, and can also contaminate surfaces, materials, and consumables.]

7.3.1.7 Body Waste Odor

[V2 7026] The system **shall** provide odor control for the body waste management system.

[Rationale: Uncontrolled waste-associated odors can have an adverse effect on crew performance and can exacerbate pre-existing symptoms of space motion sickness.]

7.3.1.8 Body Waste Trash Receptacle Accessibility

[V2 7027] Body waste management trash collection **shall** be accessible to and within reach of crewmembers using the body waste management system.

[Rationale: Waste management items that cannot be collected and contained with human waste are to be disposed of immediately after use. Waste management trash collection items are to be within reach of the crewmember so that it is not necessary to egress the waste management restraint system or to access closed compartments.]

7.3.1.9 Body Waste Management Maintenance

[V2 7029] All body waste management facilities and equipment **shall** be capable of being cleaned, sanitized, and maintained.

[Rationale: To remain hygienic, body waste management equipment is to be easily cleaned, sanitized, and maintained. Cleaning and sanitizing helps control odor and microbial growth. As part of the overall maintenance of the hygiene facilities, crewmembers are to have readily accessible trash collection for disposable personal hygiene supplies to minimize crew exposure to the used items.]

7.3.1.10 Body Waste Isolation

[V2 7101] For missions greater than 30 days, the system **shall** provide separate dedicated volumes for body waste management and personal hygiene.

[Rationale: Evidence from ISS suggests that locating personal hygiene (e.g., body cleansing, personal grooming) in the same volume as body waste management is impractical and disliked by the crew. Conducting personal hygiene in the Waste and Hygiene Compartment (WHC) limits its use by other crewmembers. Additionally, due to the effects of microgravity, the WHC volume may not be sufficiently clean to support hygiene activities. ISS crewmembers improvise spaces aboard station to conduct personal hygiene that are separate from the WHC volume, which may lead to issues with space utilization and microbial growth due to water liberation. A dedicated space for personal hygiene with appropriate surfaces that limit microbial growth needs to be provided in future vehicles.]

7.3.2 Body Waste Capacity

7.3.2.1 Body Waste Quantities

[V2 7102] The human body waste management system **shall** be capable of collecting and containing the various human body waste as specified in Table 7.3-1—Body Waste Quantities, for the expected needs of each mission and task.

[Rationale: Body waste collection is to be performed in a manner that minimizes the possible escape of feces, urine, vomitus, or menses into the habitable volume during microgravity and partial gravity operations, not only due to the high content of microbes present in the feces, but also due to the potential injury to crewmembers and hardware that could result from inadvertent discharge into the cabin. The presence of bacteria in urine is not typical for healthy crew; however, during certain medical conditions, like urinary tract infections, there could be a presence of bacteria, so precautions must consider this.

The body will generate the same quantity of fecal material as is normal in terrestrial circumstances based on food consumption and an individual's metabolism, with individual variables being evacuation frequency and water content. An individual can only evacuate the maximum value at a rate lower than average from limited food consumption inputs. Solid fecal matter is used to describe fecal material that is eliminated as discrete boli and will have surface characteristics that range from relatively dry to sticky depending on the internal water content, which is graphically demonstrated in a Bristol Stool chart derived from Heaton and Lewis, 1997. Diarrheal events are assumed to be in place of normal fecal elimination with the increased quantity based on increased water content and minor amounts of intestinal cellular material. In practice, a waste system is capable of accommodating fecal consistency across the continuum from solid low water content to diarrheal without allowing the escape of fecal material to the cabin environment. Alternatively, the urine output may be slightly greater or lower in various phases of the mission associated with gravity transitions and fluid intake levels.

Space Adaptation Syndrome (SAS) occurs in up to 70% of first-time fliers (30% of whom may experience vomiting) during the first 48 to 72 hours of microgravity. Also, a possible water landing may cause crewmembers to experience seasickness. Stowage and disposal are to be adequate for a worst-case number of involved crew, severity, and duration of symptoms, as well as the volume of gastrointestinal contents regurgitated. Vomiting and its associated odor, mainly produced by the compound butyric acid, may trigger a wave of bystander nausea and vomiting reaction in adjacent crewmembers in an enclosed space.

It is expected that female crew will have a menstruation cycle approximately every 27-31 days with a discharge of 30-50 mL of menses, with approximately 80% discharged in the first 3-4 days. The frequency and volume will vary from each crewmember. It should not be assumed that a crewmember is hormonally suppressed or that she will not have a change in her cycle or breakthrough bleeding at any point during a mission, thus appropriate capabilities of containing and disposing of menses must be accommodated.

The average values and frequencies of various body waste are representative over the entire mission (launch and return landing) and include occasional occurrences of the maximum values, which are noted in Table 7.3-1. Mass and volume values are for the biological material only; however, collection and containment will need to include both the biological material and all hygiene products required for immediate body cleaning after evacuation.

The collection capacity accounts for the healthy adult maximum output during a single event. The human body waste management system must always (nominally) be capable of collecting a *maximum fecal event, as it is unknown when a maximum event will occur. The fecal discharge related to gastrointestinal illness (diarrhea) occurs at an increased frequency but is also variable, unpredictable, and largely dependent on etiology. Terrestrial sources of infectious, pathogenic diarrhea such as Rotavirus A and Enterotoxigenic Escherichia coli (ETEC) can produce single-episode volumes as high as 1.5 L. For NASA missions, the preflight crew quarantine period (refer to NASA-STD-3001, Volume 1) is utilized to reduce the risk of infectious disease in-flight. Potential in-mission sources of comparable high-volume diarrhea is from acute radiation events such as SPEs for missions beyond low earth orbit (refer to NASA-STD-3001, Volume 1) and/or food that is not properly stored and prepared (refer sections [V2 7007] Food and Production Area Microorganism Levels, [V2 7008] Food Preparation, [V2 7010] Food Contamination Control, [V2 7015] Food System Cleaning and Sanitizing and [V2 7021] Body Waste Management System Location). Both of these potential risks need to be addressed as part of whole mission planning. The total collection volume is to accommodate diarrhea caused by likely pathogens or from diarrhea caused by salt/fluid shifts. When a diarrhea event will occur is unknown, so the body waste management system may process the collection differently, e.g., no compaction. The urinary collection system is to be capable of collecting all of the crewmember's output in succession, as well as the simultaneous evacuation of urine and feces with the presence of tissue from either sloughing or menses.]*

Table 7.3-1—Body Waste Quantities

Waste Type	Average Per Event	Maximum Per Event	Duration/Frequency
Feces[a]	Volume: 150 mL (5 fl oz) Mass: 150 g (0.33 lb) Length: 4-23 cm (0.2-9.1 in)	Volume: 500 mL (16.9 fl oz) Mass: 500 g (1.1 lb)	Average of two events per day
Diarrhea[b]	Volume: 500 mL (16.9 fl oz) Mass: 500 g	Volume: 1.5 L (50.7 fl oz) Mass: 1.5 kg	Eight events per day for up to two days
Urine[c]	Volume: 100-500 mL (3.4-16.9 fl oz) Flow Rate: 10-35 mL/s (0.34-1.2 fl oz/s) Mass: 100.7-513.8 g (0.2-1.1 lb)	Volume: 1 L (33.8 fl oz) Flow Rate: 50 mL/s (1.69 fl. oz/s) Mass: 1027.6 g (2.3 lbs)	Average of seven events per day
Vomitus	Volume: 500 mL (16.9 fl oz) Mass: (dependent on stomach contents)	Volume: 1 L (33.8 fl oz) Mass: (dependent on stomach contents)	Eight events per day for up to three days in-flight and post landing
Menses[d]	Volume: 30-50 mL (1.0-1.7 fl oz) per cycle Mass: (see footnote)	Volume: 114 mL (3.9 fl oz) per cycle Mass: (see footnote)	Approx. 80% released within the first 3-4 days of each cycle

Note:
a. Fecal material has a high-water content and is assumed to have a specific gravity of 1.0 for purposes of this specification.
b. Diarrhea values include fecal amounts.
c. Normal values for urine's specific gravity are between 1.002 and 1.028 which means that normally, a gallon of urine weighs between 8.362 and 8.579 pounds, or slightly more than water.
d. Menses mass considerations will need to accommodate for the method of collection, i.e., pads and tampons.

7.3.2.2 Fecal and Urine Elimination Concurrence

[V2 7085] The body waste management system **shall** be capable of collecting and containing all waste during simultaneous defecation and urination.

[Rationale: It is common for individuals to not be able to separate defecation and urination. Body waste collection systems design are to have sufficient capability to capture and contain both simultaneously.]

7.3.2.3 Urine per Crewmember

[V2 7035] The human body waste management system **shall** be capable of collecting and containing urine for either processing or disposal of an average total urine output volume of $V_u = 3 + 2.5t$ liters per crewmember, where t is the mission length in days.

[Rationale: Urine production on the first day after launch, i.e., flight day 0, is 3 L (101.4 fl oz) per crewmember. Urine output may be slightly greater or lower in various phases of the mission associated with gravity transitions and fluid intake levels. Reference Table 7.3-1—Body Waste Quantities for maximum output values.]

7.4 Physiological Countermeasures

7.4.1 Physiological Countermeasures Capability

[V2 7038] The system **shall** provide countermeasures to meet crew bone, muscle, sensorimotor, thermoregulation, and aerobic/cardiovascular requirements defined in NASA-STD-3001, Volume 1.

[Rationale: Exercise is used to maintain crew cardiovascular fitness (to aid in ambulation during gravity transitions, minimize fatigue, maintain cardiovascular health and function, and preserve thermoregulation capacity), to maintain muscle mass and strength/endurance, for recovery from strenuous tasks and confined postures, to rehabilitate minor muscle injuries, and to maintain bone mass. Exercise also has behavioral health benefits. Exercise is to commence as early as possible during the mission and continue throughout all mission phases in accordance with results from the Apollo crew's participation in the June 2006 Apollo Medical Summit (NASA/TM-2007-214755, The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations), and recommendations from the 2005 Operational and Research Musculoskeletal Summit. See Appendix A, Reference Documents, for complete citations.]

7.4.2 Physiological Countermeasure Operations

[V2 7040] The physiological countermeasure system design **shall** allow the crew to unstow supplies, perform operations, and stow items within the allotted countermeasure schedule.

[Rationale: The ease and the efficiency of the countermeasure system assists in the crew being able to perform their countermeasure activities. These activities are necessary to maintain crew health and fitness. It can be expected that daily countermeasure activity will occur.]

7.4.3 Orthostatic Intolerance Countermeasures

[V2 7042] The system **shall** provide countermeasures to mitigate the effects of orthostatic intolerance when transitioning from weightlessness to gravity environments and during Az (head-to-foot) vehicle accelerations defined in the sustained acceleration limits.

[Rationale: Orthostatic protection is needed to minimize medical and operational impacts. Impacts can include loss of consciousness and decreased cognitive function leading to inability to operate controls, pilot mechanics, and egress vehicle without assistance, thus jeopardizing success or safety of the crew during reentry and landing. Examples of methods that have been successfully used to prevent orthostatic intolerance include fluid/salt loading regimens to restore hydration, lower body (abdomen and leg) compression garments to prevent blood pooling, active cooling to prevent peripheral blood pooling and heat injury, and recumbent crewmember seating to protect cerebral blood flow during Az (head-to-foot) vehicle accelerations (planetary and lunar) and return to gravity (planetary).]

7.5 Medical

7.5.1 Medical Capability

[V2 7043] A medical system **shall** be provided to the crew to meet the medical requirements of NASA-STD-3001, Volume 1.

[Rationale: NASA-STD-3001, Volume 1, includes Health and Medical Care Technical Requirements required to reduce the risk that exploration missions are impacted by crew medical issues and that long-term astronaut health risks are managed within acceptable limits. The Health and Medical Care Technical Requirements and associated appendices define the health care, crew protection, and maintenance capability required to support the crew as appropriate for the specific mission destination and duration, as well as for the associated vehicular constraints.]

7.5.2 Medical Equipment Usability

[V2 7045] Medical equipment **shall** be usable by non-physician crewmembers in the event that a physician crewmember is not present or is the one who requires medical treatment.

[Rationale: Medical equipment is to be simple and easy to use and require minimal training so that non-medical personnel can administer care to ill or injured crewmembers. Medical equipment also is to have consistent interfaces to assist in crew usability.]

7.5.3 Medical Treatment Restraints

[V2 7046] The medical system **shall** provide equipment to position and restrain a patient, care provider, and supplies during treatment.

[Rationale: Patient restraints are to be capable of preventing the motion of arms and legs, allow stabilization of the head, neck, and spine, and provide attachment to the spacecraft or habitat. Care provider restraints are to allow the care provider to remain close to the patient to administer treatment but are easily removable or allow movement to access nearby equipment. Equipment restraints are to be able to safely restrain large items such as medical kits, as well as individual items.]

7.5.4 Medical Treatment, Personal Supplies, and Impacts to Environmental Systems

[V2 7115] Medical treatment, including pharmaceuticals, non-pharmaceutical crew care items, and related supplies, **shall** be evaluated for impacts on vehicle systems.

[Rationale: Medical treatment (including pharmaceuticals and non-pharmaceutical crew care items) and packaging material are subject to off-gas testing before approval for flight. For example, use of alcohol on the ISS is prohibited due to impacts to the ISS ECLSS. Use of products containing even small quantities of alcohol such as pharmaceutical syrups, topical creams, or related supplies, require a review to ensure no adverse effects to any environmental control or waste management systems. Alcohol-containing items must also be evaluated per NASA-STD-6016 to determine flammability characteristics and impacts in relation to the atmospheric parameters, especially O_2 saturation. Additionally, pharmaceuticals and related items and supplies must consider the impacts to metabolic waste and water recovery systems.]

7.6 Stowage Provision and Accessibility

7.6.1 Provision

Stowage provision includes stowage volume (e.g., containers, racks, shelves), and stowage restraints. Defined stowage space is needed to accommodate items including but not limited to crew personal items, crew hygiene and body waste supplies, medical supplies, cleaning supplies, and food, which can include temperature-controlled space to prevent degradation. Some stowed items are removed from stowage, used, and then returned to the provided provisions/location. Other items are temporarily removed from stowage, relocated to another use location, and much later stowed. Stowage design for crew access needs must be defined through iterative crew task analysis and include frequency of use, stowed item criticality, operational use/need timeline and priority, interference from/to adjacent or parallel tasks, spacesuit or PPE configuration, and anthropometry (e.g., reach, clearance). For operational efficiency, design of stowage provisions should be integrated with inventory management, labeling, and operational nomenclature.

Programs based on type of contract, maturity of the vendor, and/or verification process may consider consolidating requirements [V2 7050], [V2 7051], [V2 7052], [V2 7053], [V2 7054] *and [V2 7055] into the following requirement: "The system shall provide defined locations and stowage provisions that restrain stowed items under applicable environmental conditions (e.g., launch and landing loads,1g and/or micro and partial gravity) and enable crew access within operational time constraints as defined by crew task analysis."*

7.6.1.1 Stowage Provisions

[V2 7050] The system **shall** provide for the stowage of hardware and supplies, to include location, restraint, and protection for these items.

[Rationale: Some stowed items are removed from stowage, used, and then returned to the provided provisions/location. Other items are temporarily removed from stowage, relocated to another use location, and much later stowed.]

7.6.1.2 Personal Stowage

[V2 7051] The system **shall** provide a stowage location for personal items and clothing.

[Rationale: Stowage locations for personal items and clothing aids crew morale and well-being. When integrated with inventory management, labeling, and operational nomenclature, the stowing of and access to these personal items are accomplished efficiently.]

7.6.1.3 Stowage Location

[V2 7052] All relocatable items, e.g., food, EVA suits, and spare parts, **shall** have a dedicated stowage location.

[Rationale: To maintain a high level of efficiency in crew operations, it is important to locate items within easy reach of their point of use or consumption. Although difficult to achieve completely, all efforts are to be made to provide stowage for items manifested and flown. An important consideration is the need to keep the translation pathways clear and protect the volume necessary for the crew to execute their tasks safely and efficiently. Stowage is not to hinder the access to any emergency equipment.]

7.6.1.4 Stowage Interference

[V2 7053] The system **shall** provide defined stowage locations that do not interfere with crew operations.

[Rationale: Having defined stowage locations supports efficient operations and helps prevent the stowage system from interfering with operations such as translation and vehicle control. Care is to be taken when designing the stowage system so that clear translation can occur in the event of an emergency. To maintain a high level of efficiency in crew operations, it is important to locate items within easy reach of their point of consumption.]

7.6.1.5 Stowage Restraints

[V2 7054] The system **shall** provide the capability to restrain hardware, supplies, and crew personal items that are removed or deployed for use as defined by crew task analysis.

[Rationale: Stowed and deployed items are to be restrained so that they are secure for crew use and prevent uncontrolled movement causing injury, damage, or inefficient task performance under expected conditions for acceleration, vibration, or crew contact. Restraints must also be designed to facilitate operations in expected gravity environments. For example, in microgravity, restraints must be retainable in an open or loosened position to facilitate stow/unstow of items during stowage operations. Stowage restraints help protect the crew from injury and equipment from damage or loss and ensure that stowed or deployed items remain where required during operations and crew tasks.]

7.6.2 Accessibility

Accessibility means having the ability to reach and retrieve objects with relative ease. The following subsections define requirements for implementing this feature.

7.6.2.1 Priority of Stowage Accessibility

[V2 7055] Stowage items **shall** be accessible in accordance with their use, with the easiest accessibility for mission-critical and most frequently used items.

[Rationale: Items are to be stowed to promote efficient retrieval and operations.]

7.6.2.2 Stowage Operation without Tools

[V2 7056] Stowage containers and restraints **shall** be operable without the use of tools.

[Rationale: To maximize the use of crew time, the stowage system is to permit crew access and reconfiguration without the use of tools.]

7.6.2.3 Stowage Access while Suited

[V2 7057] The stowage system **shall** be accessible by a suited crewmember.

[Rationale: The stowage system must be designed to include features that allow a suited crewmember to access, open, close, or manipulate stowed items. This means the integrated system must accommodate suit constraints and volumetric requirements. This applies to normal as well as contingency operations.]

7.6.3 Identification System

[V2 7058] The stowage identification system **shall** be compatible with the inventory management system.

[Rationale: Space Shuttle and ISS experience has shown that stowage management and identification—the knowledge of the quantity, location, and type of each supply—is crucial for mission planning and maintaining crew productivity. Quantity and location are not the only aspects of stowage identification. Stowage, labeling, inventory tracking, and operational nomenclature are also considered when developing an integrated system.]

7.7 Inventory Management System

7.7.1 Inventory Tracking

[V2 7059] The system **shall** provide an inventory management system to track the locations and quantities of items (including hazardous trash) throughout the mission.

[Rationale: Space Shuttle and ISS experience has shown that inventory/stowage management—the knowledge of the quantity and location of each type of supply—is crucial for mission planning and maintaining crew productivity. Quantity and location are not the only aspects of inventory tracking. Stowage, labeling, and operational nomenclature are also considered when developing an integrated system.]

7.7.2 Inventory Operations

[V2 7060] The system **shall** be designed to allow inventory management functions to be completed within the allotted schedule.

[Rationale: The inventory management system is to be efficient, and the amount of time required by the crew to perform the functions of the system minimized. A flexible system allows for changes in stowage locations or quantities any time during missions. Lessons learned in past spaceflight have indicated that past inventory operations have exceeded the allocated time required to accomplish the tasks. This can interfere with other expected tasks.]

7.7.3 Nomenclature Consistency

[V2 7061] The nomenclature used to refer to the items tracked by the inventory management system **shall** be consistent with procedures and labels.

[Rationale: It is imperative that spaceflight operations personnel, including all ground controllers and crewmembers, communicate using common nomenclature that unambiguously and uniquely defines all hardware and software items. This nomenclature is also to be common among all operational products, including commands, procedures, displays, planning products,

reference information, system handbooks, system briefs, mission rules, schematics, and payload operations products.]

7.7.4 Unique Item Identification

[V2 7062] Items that need to be uniquely identified **shall** have a unique name.

[Rationale: Unique names for inventory items assist in the location and clear identification of the items. This promotes efficiency and reduces the likelihood of mis-selection of items for tasks. This also assists to minimize training.]

7.7.5 Interchangeable Item Nomenclature

[V2 7063] Items within the inventory management system that are identical and interchangeable **shall** have identical nomenclature.

[Rationale: Names for inventory items assist in the location and clear identification of the items. This promotes efficiency and reduces the likelihood of mis-selection of items for tasks.]

7.8 Trash Management System

7.8.1 Provision

7.8.1.1 Trash Accommodation

[V2 7064] The system **shall** provide a trash management system to contain, mitigate odors, prevent release, and dispose of all expected trash.

[Rationale: All wet and dry waste, including food, sharp items, biological, chemical, and radioactive materials must be planned for and accommodated within the system for the duration of the mission until planned disposal. Task analysis identifies waste generating tasks, waste types and quantities, biological content, environmental conditions (including gravity), odor, and other relevant task conditions. Odors may be mitigated by neutralizing, removing, or containing trash. Considering potential health effects to the crew, waste containment systems are to control microbial growth and not allow inadvertent escape of biological or chemical contaminants and protect crew from inadvertent injury from sharp items and medical equipment. A good practice is to separate and isolate hazardous and non-hazardous waste containment, such as body waste and food packaging waste. Hazardous waste containers are to be clearly and visibly identified with text and/or symbolic labeling. If multiple types of hazardous waste are accumulated in a single container, the outermost containment label indicates the highest level of hazard (e.g., toxicity, biohazard) contained. Trash stowage volumes and locations are to be defined to ensure stored waste does not interfere with crew operations. The design must consider how crew will operate the system in their intended environment: How will crew prevent waste particles from escaping in microgravity; How will the containment system withstand changing pressure

environment; What is the planned duration of containment until trash can be removed from the vehicle.]

7.8.1.2 Trash Volume Allocation

[V2 7065] Trash stowage volumes **shall** be allocated for each mission.

[Rationale: The trash plan defines the types and quantities of trash expected during mission operations. Trash buildup occurs, especially on missions where there is no expendable vehicle to carry away the trash, or capability to jettison or recycle the waste. Dedicated trash stowage volumes and locations are needed and are to be coupled with appropriate packaging and containment. The volume and mass allocations for body waste are referenced in Table 7.3-1 of requirement [V2 7102] Body Waste Quantities.]

7.8.1.3 Trash Stowage Interference

[V2 7066] The system **shall** provide defined trash stowage that does not interfere with crew operations.

[Rationale: This requirement is intended to prevent the trash system from interfering with normal operations such as translation and vehicle control. Design requirements are to ensure that the trash system does not interfere with translation during emergency events. Additionally, in an effort to maintain a high level of efficiency in crew operations, it is important to locate trash receptacles within easy reach of their point of use.]

7.8.2 Labeling of Hazardous Waste

[V2 7069] The hazard response level (HRL) of all liquids, particles, gases, and gels **shall** be labeled on the outermost containment barrier in location(s) visible to crew.

[Rationale: Hazard response labeling informs the crew of appropriate personal protective equipment (PPE) and clean-up response in the event of an unintended release. Labeling of the hazardous waste enables the tracking as inventory per [V2 7059] Inventory Tracking. Assessment of liquids, gels, gasses, and particles used in the habitable volume are performed by NASA JSC Toxicology, BioSafety, Materials, and Environmental Control teams to determine appropriate HRL. System and hardware developers can submit information to NASA per JSC-27472, Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals to be Flown on Manned Spacecraft. The requirements for HRL labeling are defined in JSC-27260, Standard Flight Decal Catalog.]

7.9 Behavioral Health and Sleep

7.9.1 Sleep Accommodation

[V2 7070] The system **shall** provide volume, restraint, accommodations, environmental control (e.g., vibration, lighting, noise, and temperature), and degree of privacy for sleep for each crewmember, to support overall crew health and performance.

[Rationale: The sleep accommodation requirements depend primarily on the gravity environment and the mission duration. However, in microgravity environments, restraints are provided to secure blankets and maintain positioning, with a range from knees-to-chest to full-body stature. Evidence from short- and long-duration missions and other relevant isolated, confined, and extreme environments suggests that environmental factors such as noise, temperature, vibration, and light inhibit sleep and impact well-being in space. Individual crew preferences vary, so individual control of the sleep environment is necessary to ensure adequate sleep and maintain physical and behavioral well-being during missions. Examples of sleep accommodations provided to each crewmember include clothing, bedding, ear plugs, light blockers, eye masks, etc. (See section 8.5, Restraints and Mobility Aids, in this NASA Technical Standard.).]

7.9.2 Behavioral Health and Privacy

[V2 7071] For long duration missions (>30 days), individual privacy facilities **shall** be provided.

[Rationale: Isolation, confinement, mission task demands, social density, and other associated aspects of spaceflight can lead to stress, which tends to increase with mission duration. Therefore, privacy is a countermeasure needed to protect the behavioral health of the crew, particularly in spaceflight vehicles with a relatively smaller volume. Terrestrial literature has further shown that greater distance between workstations is associated with improved job performance relative to smaller distances and that increased privacy is related to decreased emotional exhaustion. Providing private accommodations for crew to accommodate sleep and social retreat will allow for improved sleep quality and completion of tasks with reduced distractions and will allow for crew to temporarily withdraw for emotional restoration. Tasks that require privacy, such as private medical or psychological conferences, will also need to be facilitated by accommodations for visual and auditory privacy.]

7.9.3 Partial-g Sleeping

[V2 7073] The system **shall** provide for horizontal sleep surface areas for partial-g and 1-g environments.

[Rationale: The sleeping area volume is to accommodate crew body sizes in all gravity environments. Partial-g, i.e., lunar (1/6) and Mars (1/3) gravity, defines the orientation of the volume. Orientation and body support (e.g., cushioning) must be considered in partial-g environments.]

7.10 Clothing

7.10.1 Clothing Quantity

[V2 7074] Clean, durable clothing **shall** be provided in quantities sufficient to meet crew needs.

[Rationale: Requirements are to be based on acceptable definitions of "clean" and "durable." Requirements are then to include the number of days that an individual item of clothing can be worn before laundering or disposal and, for laundered clothing, the lifetime of the clothing item. Clothing is to be designed so it can be donned and doffed in all situations without assistance from other crewmembers.]

7.10.2 Clothing Exclusive Use

[V2 7075] Clothing **shall** be provided for each individual crewmember's exclusive use.

[Rationale: Requirements for exclusive clothing use are to include considerations for individual stowage areas, clothing identification (particularly if clothing is laundered), sizing, and individual preference accommodation.]

7.10.3 Clothing Safety and Comfort

[V2 7076] Clothing **shall** be comfortable in fit and composition, for the environment, e.g., temperature and humidity, in which it will be worn.

[Rationale: Requirements for clothing types are to be based on anticipated crew activities, e.g., exercise, maintenance, lounging, work, etc., and gravity environments, e.g., very loose clothing and shoes would be inappropriate in a microgravity environment. Layering of clothing may accommodate temperature and personal preferences. (See Figure 6.2-2—Crew Health Environmental Limits, [V2 6012] Crew Health Environmental Limits and [V2 7041] Environmental Control During Exercise.) Clothing design is also dependent on the range of crew sizes as defined in the physical characteristics database. (See section 4.1 Physical Data Sets in this NASA Technical Standard.) Clothing material is to be assessed as stated in NASA-STD-6016. Material selection includes evaluation for material degradation that produces lint or fuzz.]

7.11 Housekeeping

7.11.1 Accessibility for Cleaning

[V2 7079] The system **shall** provide sufficient volume to access areas that need to be cleaned and perform housekeeping duties.

[Rationale: Access to areas that need to be cleaned include physical access (e.g., panels and covers can be easily removed) and the provision of sufficient volumes for cleaning activities and associated hardware. The full-size range of personnel with appropriate cleaning tools and equipment is to be able to access all areas for routine cleaning. Areas such as vents that need to be cleaned regularly need to be easily accessible. Complex access procedures (e.g., disassembling panels, disconnecting alarms) add time and frustration to task performance. Fixed equipment is to be designed to not have to be unsecured and moved for routine cleaning. Inaccessible areas are to be closed off to prevent the accumulation of trash, dirt, and dust particulates.]

7.11.2 Particulate Control

[V2 7080] The system **shall** be designed for access, inspection, and removal of particulates that can be present before launch or that can result from mission operations.

[Rationale: Manufacture, assembly, or other operations in a terrestrial or partial-g environment may accumulate residue and debris. This residue may then contaminate the spacecraft during flight or reduced-gravity environments. System development specifications are to ensure that crews can access residue accumulations for removal.]

7.11.3 Microbial Surface Contamination

[V2 7081] The system **shall** provide surfaces that are microbiologically safe for human contact.

[Rationale: Microbiologically safe surfaces are essential to prevent infection and mitigate risk to crew health and performance. Assessing the microbiological safety of internal surfaces relies primarily on the enumeration and identification of viable, medically significant microorganisms (bacteria and fungi) that are known to cause disease. Historically, microbial concentrations on internal surfaces of crewed spacecraft have been controlled by the selection of materials that do not promote microbial growth and can be cleaned/disinfected in-flight. Medical significance of microorganisms and allowable levels of microorganisms are set based on guidance from the JSC Microbiology Laboratory. Program level requirements for surface contamination include considerations for factors such as intended uses, vehicle architecture, and mission duration. Considerations must be taken for scenarios where there is a period of dormancy or uncrewed operations.]

7.11.4 Surface Material Cleaning

[V2 7082] The system **shall** contain surface materials that can be easily cleaned and sanitized using planned cleaning methods.

[Rationale: Program requirements are to be established so that surface materials such as highly textured materials are assessed for this feature. The evaluation of materials associated with spacesuits (internally and externally) are to be assessed as stated in [V2 11126] Suit Materials Selection Cleanability.]

7.11.5 Cleaning Materials

[V2 7083] The system **shall** provide cleaning materials that are effective, safe for human use, and compatible with system water reclamation, air revitalization, waste management systems, spacesuits and other spacecraft materials.

[Rationale: Program requirements are to be established so that cleaning materials are assessed for these features. Effective cleaning materials leave a cleaned surface ready for use without the need for additional cleaning. For example, an effective window cleaning material leaves the window with no accumulation, streaking, or any other artifact that could interfere with the use of the window (photography or piloting tasks). On the other hand, cleaning material used on a dining table could be considered effective even with the presence of streaks or accumulation, as long as the surface is safe on which to prepare, serve, and consume food. Cleaning materials are not to promote degradation of the items being cleaned beyond normal wear and tear, for example labels and barcodes could be wiped away or made illegible over time with repetitive exposure to harsh cleaning materials. Considerations for both the strength and use of each cleaning material and the material make-up of each item being cleaned is needed to prevent this occurrence. This could also include the need for physical debris removal from the outer layer of the suit when exposed to the environment outside the habitable space. Additionally, considerations for the cleaning and sanitizing the inside portions of the suit that may have been exposed to human secretions, waste or medications applied prior to donning are important to avoid health impacts. Materials selected will need to consider the materials selected as required in [V2 11126] Suit Materials Selection Cleanability.]

7.11.6 Condensation Limitation

[V2 6058] The system **shall** prevent condensation persistence on surfaces within the vehicle.

[Rationale: The presence of free water can promote the growth of microbial organisms, which poses a hazard to human health. The system is to provide controls and mitigation steps to prevent the formation of condensate on internal surfaces for a length of time, thus preventing microbial growth to unacceptable levels. Initial microbial concentration, the probable types of organisms, the porosity of the surface materials, and exposure can affect the acceptable persistence of the condensate based upon crew health risk mitigation. Examples of moisture buildup from previous spaceflight missions that resulted in fungal growth include non-insulated cold surfaces and designed operations, which moisten surfaces (such as wetting a cloth) without appropriate drying. Condensation on a non-ventilated surface will be difficult to dry. Current ISS requirements provide some flexibility in allowable condensate persistence for areas determined to have minimal crew health risk.]

7.12 Recreational Capabilities

[V2 7084] The system **shall** provide individual and team-oriented recreational capabilities for the crew to maintain behavioral and psychological health.

[Rationale: Appropriate recreational facilities depend on the nature and duration of the mission. Program development requirements are to provide time and resources for psychological assessment of crew needs. The system design is to include recreational facilities, materials, and operational accommodations identified in these assessments.]

8. ARCHITECTURE

Architecture is defined as the arrangement and configuration of the functional areas where the crew lives and works. This includes any items necessary for translation, restraints and mobility aids, hatches, windows, and lighting. For detailed requirements to accommodate the physical characteristics of the crew, see section 4, Physical Characteristics and Capabilities, in this NASA Technical Standard. Accommodations for the specific functions that occur within the architecture of the habitat are addressed in section 7, Habitability Functions, in this NASA Technical Standard. Environmental qualities of the architecture are in section 6, Natural and Induced Environments.

See Appendix C for definitions of Pressurized Volume, Non-habitable Volume, Dedicated Equipment Work Volume and Habitable Volume.

8.1 Volume

8.1.1 Volume Allocation

[V2 8001] The system **shall** provide the defined habitable volume and layout to physically accommodate crew operations and living.

[Rationale: The architectural layout of space for living and working is designed to provide defined locations and volumes that allow for expected crew activities, including mission operations, habitability functions, and translation. Required volume is a function of the number of crew, number of mission and contingency days, and the crew activities. Design and layout of functional volumes are guided by function and task analysis, as well as iterative process of design and evaluation. Task attributes such as operational flow, frequency, dependencies, compatibility, interference, equipment, crew postures and gravity environment must be considered in the functional layout and interfaces. Tasks that are sensitive or incompatible with other activities, such as food prep, body self-inspection and cleansing, and use of the lavatory, are to be separated or isolated to avoid contamination or detrimental impacts to performance, health, or well-being. Private self-inspection following use of the lavatory will impose additional volume needs in microgravity or very low fractional environments to ensure that waste has separated from the body and clothing and not recirculated in adverse trajectories – something that is less necessary in 1g or higher fractional gravities. Longer mission duration will increase functional volume needs for accommodation of stowage, increased volume for exercise equipment including exercise performance, medical treatment facilities and equipment, as well as crew sleep, recreation and privacy for behavioral health. Volume, size, and layout of medical treatment facilities and equipment will need to consider number of crewmembers, level of care, mission duration, crew activities, and the likelihood that multiple crewmembers may require simultaneous medical attention. For spacecraft volume design methodology and best practices, refer to SA-16-156, Level II JSC CMO HMTA Position on NHV and Internal Layout Considerations for Exploration Missions; NASA/TP-2014-218556; NASA/SP-2010-3407, section 8.2, Overall Architectural Design, and JSC 63557 Net Habitable Volume Verification Method.]

8.1.2 Functional Arrangement

[V2 8005] Habitability functions **shall** be located based on the use of common equipment, interferences, and the sequence and compatibility of operations.

[Rationale: Design for any system, function, or activity is to be based on the logical sequence and smooth flow of activities that are to occur. Generally, the most efficient layout is to place functions adjacent to each other when they are used sequentially or in close coordination. There are some limitations to this general rule, however. Adjacent positions are not to degrade any of the activities within the stations, nor is the positioning to degrade any of the activities in surrounding stations. General adjacency considerations, beyond simple activity flow, include transition frequency, sequential dependency, support equipment commonality, physical interference, traffic interference, privacy, confidentiality, noise output and sensitivity, lighting, vibration, simultaneous use or adjacent use by multiple crewmembers, and contamination.]

8.1.3 Interference

[V2 8006] The system **shall** separate functional areas whose functions would detrimentally interfere with each other.

[Rationale: Co-location of unrelated activities can degrade operations, resulting in increased workload and operational delays. This consideration will be difficult to meet in a small volume, but every effort is to be made to separate functions and capabilities that could operationally conflict with each other or that produce environmental conditions that conflict with other tasks, e.g., glare, noise, vibrations, heat, odor.]

8.2 Configuration

Configuration refers to the visual aids that inform crewmembers about their spatial orientation and location within the spacecraft. This section describes requirements for consistent visual cues for orientation and location within and among modules.

8.2.1 Spatial and Interface Orientation

[V2 8007] The system **shall** have consistent spatial and interface orientations relative to a defined vertical orientation.

[Rationale: The human working and living position is to be established with respect to a defined local vertical, especially when there is no gravity cue that identifies the up or down orientation. To promote efficient performance and avoid disorientation or errors, the system designer must define the spatial and interface directional orientation using design features such as visual orientation cues (e.g., labeling), orientation of work surfaces, positioning of displays and controls, etc. Maintaining a consistent orientation of interfaces minimizes crewmember rotational realignments needed to perform tasks that have directionally dependent components such as reading labels and displays. Inconsistent and varied display and control orientations

may contribute to operational delays or errors. Given the complexity of some operations (e.g., piloting), a single orientation for all controls, displays, and labels may not be possible; but the design is to minimize crewmember repositioning to efficiently perform a task. This requirement is meant to ensure that all equipment at an interface is aligned with respect to the crewmember's head so that an operating crewmember only needs to adjust body orientation slightly in pitch and yaw at a workstation but does not need to adjust body orientation in roll. Orientations are to be consistent within a given functional volume where crew may interface with multiple different elements. Separate functional volumes (e.g., lab module, cargo module, observation cupola) may each have their own local orientation, different from other volumes, but internally consistent to support crew interfaces.]

8.2.2 Location Identifiers

[V2 8010] A standard location coding system **shall** be provided to uniquely identify each predefined location within the system.

[Rationale: Location coding provides a clear method of referring to different locations within the vehicle habitat and serves as a communication and situational awareness tool when traversing the vehicle or unstowing/stowing equipment.]

8.2.3 Location Aids

[V2 8011] The system **shall** provide aids to assist crewmembers in locating items or places within the system and orienting themselves in relation to those items or places.

[Rationale: Crewmembers need visual cues to help them quickly adjust their orientation to a local vertical position. When adjacent workstations have vertical orientations differing by 45 degrees or greater, visual demarcations need to be provided to prevent inadvertent use of the adjacent workstation elements.]

8.3 Translation Paths

Translation paths are to be designed so traffic flow does not detrimentally interfere with other unrelated activities such as sensitive spacecraft control, routine servicing, experimentation, eating, sleeping, and relaxation. Pathways should be clear of hazards (e.g., protrusions, entanglements (cables, hoses), free-floating equipment) to avoid crew injury or equipment damage. Pathways that dead-end or may have unpassable hazards (i.e., open ignition source) should be sized to allow crewmembers to turn around and retreat.

8.3.1 Intravehicular Translation Paths

[V2 8013] The system **shall** provide intravehicular activity (IVA) translation paths that allow for safe and unencumbered movement of suited and unsuited crew and equipment.

[Rationale: Translation paths are the defined volumes reserved for safe and efficient movement of crew and equipment for nominal, contingency, or emergency operations. Pathway size and shape is based on task analysis to take into account needs and constraints such as the location, type, and level of activity that will occur in functional areas or workstations (e.g., movement within recreation area, cargo translation between vehicle and module, temporary rack rotation); the crew movement postures (e.g., upright or prone position, pushing or pulling equipment); the type of equipment being translated; the number of crew (simultaneous or sequential flow); and the configuration of crew (unsuited, suited unpressurized, suited pressurized, PPE). Translation paths are to be designed so traffic flow does not detrimentally interfere with other unrelated activities such as sensitive spacecraft control, routine servicing, experimentation, eating, sleeping, and relaxation. Lessons learned from the ISS indicate that translation paths around the ISS eating area have disrupted crew rest and relaxation required during meals. Pathways are to be clear of hazards (e.g., protrusions, entanglements (cables, hoses), free-floating equipment) to avoid crew injury or equipment damage. Pathways that dead-end or may have unpassable hazards (i.e., open ignition source) are to be sized to allow crewmembers to turn around and retreat. Slip, trip and fall hazards must be taken into account for any translation paths that may be used in full or partial gravity This requirement also applies to pressurized tunnels, which allow for translation between docked pressurized elements, and are designed to allow for static or dynamic forces and variations of alignment (such as uneven terrain) without imparting forces onto the elements.]

8.3.2 Emergency Escape Paths

[V2 8014] The system **shall** provide unimpeded and visible emergency escape routes commensurate with the hazard analyses and response concepts.

[Rationale: Factors that contribute to successfully meeting this technical requirement include the following:

a. Having pre-planned emergency escape routes that are identified early in the design process. This begins with analysis to identify system hazards, time-to-effect of hazards or emergencies, and crew tasks which define the system design needs and constraints.

b. Ensuring the identified routes are:
(1) free of obstructions (snags, protrusions, stowed items, etc.)
(2) clearly marked to guide the way to safety (e.g., with color-coded strip lighting, photoluminescent decals, etc.)
(3) illuminated for emergency tasks
(4) designed to require a minimal number of operations for passage (such as awkward turns or hatch operations).

c. Having pathway markings that are visible during power loss. If multiple escape paths lead to different areas depending on the emergency, the correct pathway must be made clear to crew. An open hatchway is insufficient identification of an egress route.

d. When considering time required, accounting for the entire route the crew would need to take to get to safety as well as time to access and carry necessary equipment.

e. Sizing the route to accommodate for the dimensions of the users, including suits and special protective/survival equipment, and the number of concurrent users, including possible rescue personnel.]

8.3.3 Assisted Ingress and Egress Translation Path

[V2 8020] The system **shall** provide translation paths that accommodate the ingress and egress of a crewmember assisted by another crewmember.

[Rationale: An injured, deconditioned, or incapacitated crewmember may be unable to ingress or egress a vehicle on their own and may need assistance from another person or the aid of a device. An ingress or egress translation path is to accommodate the crewmember being assisted, the assisting personnel, and any necessary equipment, e.g., medical equipment. The conditions (e.g., ingress/egress orientation with respect to gravity environment, all planned pressurized or unpressurized suits, number of personnel) and constraints (e.g., egress time) for assisted ingress and egress are to be determined by concept of operation and task analysis.]

8.3.4 EVA Translation Path Hazard Avoidance

[V2 11005] EVA translation paths **shall** be free from hazards.

[Rationale: Safety is paramount for all EVA tasks. When translation paths and mobility aids are properly provided, they can reduce the hazards associated with colliding with hardware, intruding into keep-out zones, contacting sharp edges and burrs, or contacting contaminated surfaces. Without predefined translation paths and carefully located mobility aids, items or equipment not intended as mobility aids can be damaged from induced loads, such as grabbing, pushing, and pulling.]

8.4 Hatches and Doorways

See Appendix C for definitions of Hatch, Hatch Cover, Hatchway, Door and Doorway.

8.4.1 Operability

8.4.1.1 Hatches and Door Operation without Tools

[V2 8022] Hatches and doors **shall** be operable on either side by a single crewmember without the use of tools in expected gravity conditions, orientations, suit configurations, and operational configurations.

[Rationale: Hatch operation includes equalizing pressure, unlatching/opening, and latching/closing the hatch to enable translation through or isolation of pressurized volumes.

Hatches must be designed for single crew operation since they may be in a small volume or in an escape route and need to be quickly opened by the first crew there. Tool use for manual pressure equalization and opening/closing hatches is prohibited to avoid hatch operation delays or failures. Lost or damaged tools may prevent hatches from being opened/closed resulting in loss of crew (LOC) or loss of mission (LOM). Gravity conditions, hatch orientations, and suit configurations are considered in hatch design and operations as they impact crew task posture, strength motion, deconditioning, and safety. When there are program/project needs for hatch and door tool provisions, an exception or waiver to this document may be necessary.]

8.4.1.2 Unlatching Hatches

[V2 8023] Hatches **shall** require two distinct and sequential operations to unlatch.

[Rationale: Inadvertent hatch opening, and subsequent cabin depressurization would be catastrophic. Requiring two separate, distinct operations helps to ensure that the hatch will not be unlatched through accidental contact.]

8.4.1.3 Hatch and Door Operating Times

[V2 8024] For nominal operations, hatches and doors **shall** be operable by a single crewmember in no more than 60 seconds, from both sides of the hatch.

[Rationale: Hatch operation includes unlatching/opening or latching/closing the hatch. Excessively long operating times can delay crews on both sides of a hatch, which would prevent ingress or egress. The hatch operating requirement of 60 seconds is based on engineering judgment related to easily operable hatch design without complicating hatch design and includes time for a deconditioned crewmember to operate hatch. This does not preclude a program/project from implementing more strict design requirements. For guidance regarding emergency escape time, see requirement [V2 8014] Emergency Escape Paths in this NASA Technical Standard.]

8.4.1.4 Hatch and Door Operating Force

[V2 8025] The forces required to operate each crew interface for the hatches and doors **shall** be within the crewmember strength defined by requirement [V2 4104] Crew Operational Loads for the worst-case pressure differential and anticipated encumbering equipment and clothing.

[Rationale: All crewmembers are to be able to operate hatches and doors. Designing operating forces to the strength of the weakest crewmember ensures the crew can perform activities related to safety and to LOM. Determination of anticipated worst-case parameters can be made through a detailed task analysis. For example, in 1997, a Progress collided with Mir and caused a cabin depressurization; the crew were unable to close the hatch due to the force of the rushing air.]

8.4.2 Hatchway and Doorway Design

8.4.2.1 Hatchway Size and Shape

[V2 8027] Hatchways and doorways **shall** be sized and shaped to accommodate all planned translations, including unrestricted passage of a suited crewmember and crewmembers carrying cargo or equipment.

[Rationale: A pressurized-suited crewmember represents a situation where the crewmember's size is enlarged in many dimensions by virtue of the suit. Should a situation arise where the crewmember needs to move through hatchways and doorways while suited, especially in an emergency situation, the hatchways and doorways are to be large enough for the crewmember to pass safely and efficiently. Planned tasks include all nominal and planned contingency tasks. Also, reconfiguration of a spacecraft may require crewmembers to transport potentially large pieces of equipment across hatchways and doorways. Hatchway size must also consider the capability for a rescuing crewmember to be able to transport an incapacitated crewmember without being hampered by inadequate hatchway or doorway sizes. Hatchways and doorways may be designed to accommodate translation of robotic agents, but still accommodate crewmembers and their equipment.]

8.4.2.2 Pressure Equalization across the Hatch

[V2 8028] Each side of each hatch **shall** have manual pressure equalization capability with its opposite side, achievable from that side of the pressure hatch by a suited or unsuited crewmember.

[Rationale: Air pressure is to be equalized on either side of a hatch to safely open the hatch. In some vehicle failure scenarios, non-manual methods for pressure equalization may fail. Manual pressure equalization enables hatch opening regardless of vehicle status. This capability does not need to be physically located on the hatch if task analysis supports a different location.]

8.4.2.3 Visibility across the Hatch

[V2 8029] The system **shall** provide a window for direct, non-electronic visual observation of the environment on the opposite side of the hatch.

[Rationale: Direct visual observation of the environment on the opposite side of the hatch allows the crew to determine the conditions or obstructions for safety purposes, such as the presence of fire or debris. Windows do not have the failure modes associated with cameras and display systems that may not be operable during emergencies when most needed. While cameras or other sensors may be used to supplement the situational awareness afforded by a window, those systems alone do not meet the intent of this requirement. The minimum window field of view and what environmental conditions must be detected for crew and vehicle safety will be determined via task analysis, and verification is to be done through the observation of the volume on the opposite side of the hatch in both viewing directions (internal to external and vice-

versa for crew and vehicle safety) via a flight-like hatch window in flight-like configuration to determine if the objects or conditions identified via task analysis can be detected. Hazards may be assessed to determine if sensors, cameras, and procedural processes can be considered in lieu of windows for certain vehicles/modules not meant for habitation.]

8.4.3 Hatch and Door Design

8.4.3.1 Hatch, Hatch Cover and Door Interference

[V2 8030] When opened, hatches, hatch covers and doors **shall** allow for unrestricted flow of traffic.

[Rationale: Open hatches, with or without hatch covers, and doors are not to protrude into translation space and inhibit the safe and effective movement of both the crewmembers and any equipment they need to move from one location to another. In addition, open hatches, with or without hatch covers, and doors are to allow for a clear emergency translation pathway.]

8.4.3.2 Hatch Closure and Latching Status Indication

[V2 8031] Pressure hatches **shall** indicate closure and latching status on both sides of the hatch.

[Rationale: Indication of hatch closure and latch status on both sides of the hatch allows both ground personnel (launch pad) and crewmembers to verify that each hatch is closed and latched. For cases in which multiple latches must close in order to secure a hatch, this requirement applies to the system-level latched status of the hatch. By providing both closure and latch position status, proper security of the hatch can be verified. Hatch closure implies that the hatch is in proper position to be latched.]

8.4.3.3 Hatch Pressure Indication

[V2 8032] Pressure hatches **shall** indicate, viewable from both sides of the hatch, pressure differential across the hatch.

[Rationale: Indication of pressure difference on both sides of the hatch allows both ground personnel and crewmembers to see the changes in pressure across the hatch and to know when the pressure difference is low enough to safely open the hatch. Use of numerical values, color, or other cues can be used to indicate when it is safe to operate a hatch. Direct, non-electronic pressure difference measurement and display on both sides of the hatch will allow both ground personnel and flight crew to see a direct measurement and view the changes in pressure across the hatch to know when the pressure difference is low enough to safely open the hatch, without reliance on mental calculations or being subject to failure modes of an electronic display. This function is especially needed during an emergency. Direct measurement display does not need to be directly on the hatches but must be viewable by the crew at the hatch worksite while operating the hatch.]

8.4.4 No Drag-Throughs

[V2 8101] Hatchways **shall** be clear of drag-throughs.

[Rationale: During emergencies, hatchways may need to be closed quickly; and their function must be un-inhibited by items. Hatchways must remain clear of items, including, but not limited to, cargo, cables, and wires. For example, during a cabin depressurization, the crew will need to immediately close a hatch, which cannot be inhibited, like what occurred on Mir when there was a resupply vehicle collision with the U.S. habitat module, and the crew could not quickly close the hatch because of the obstructions in the hatchway.]

8.5 Restraints and Mobility Aids

In reduced gravity and dynamic acceleration environments, restraints are needed by crew to position and stabilize themselves and protect from injury. Restraints are also needed to react to operational forces, such as during hatch opening/closing operations. The design and placement of crew restraints begins with crew task and worksite analysis to determine physical task factors such as crew body positions (e.g., workstation, sleep, personal hygiene, medical treatment), suit configuration (e.g., suited or unsuited, pressurization, gloves, boots), movement action (e.g., single- or two-handed operation), movement direction, range of motions, force, duration, etc.

8.5.1 Restraints for Crew Tasks

[V2 8033] The system **shall** provide restraints for expected crew operations.

[Rationale: In reduced gravity and dynamic acceleration environments, restraints are needed by crewmembers to position and stabilize themselves and protect from injury across a wide range of operations as identified by task analysis. Restraints are also needed to react to operational forces, such as during hatch opening/closing operations. In the absence of intentional restraints, ISS experiences have shown that crew will use convenient physical features to stabilize themselves. Hardware failures have occurred due to unplanned use of features that were not designed to withstand loads or repeated use. The design and placement of crew restraints begins with crew task and worksite analysis to determine physical task factors such as gravity conditions (e.g., micro, partial, or 1-g), crew body positions (e.g., workstation, sleep, personal hygiene, medical treatment), operational configuration (e.g., suited or unsuited, pressurization, gloves, boots, PPE), movement action (e.g., single- or two-handed operation), movement range and direction, force, duration, etc. Worksite analysis is an extension of the task analysis to further describe the expected physical interactions between the crew and their system interfaces.

Factors that contribute to satisfying this requirement are as follows:

a. *Restraints do not impede task performance.*

b. *Potential gravity conditions (e.g., micro, partial, or 1-g) are accommodated for.*

c. Potential crew body positions (e.g., workstation, sleep, personal hygiene, medical treatment) are accommodated for.

d. Potential body postures and joint angles are accommodated for. Suited posture, joint angles, and range of motion are unique and are factored into the design of suit restraints for EVAs, airlock, etc.

e. Potential operational configurations (e.g., suited or unsuited, pressurization, gloves, boots, PPE) are accommodated for.

f. Intended movement actions (e.g., single- or two-handed) are decided and accommodated for.

g. Potential movement range and direction are accommodated for.

h. Potential effects from use duration (e.g., pain or fatigue from an extended duration) are accommodated for.

i. The amount of force a crewmember could potentially impose on a restraint (and vice-versa) is accommodated for.

j. Standardizing the form factor of restraints to help the crew easily identify and use intentional restraints.

Factors that could improve ease of use, cost, and complexity are as follows:

a. Designing restraints for multi-purpose use such as designing cargo straps to also be used as foot restraints during cargo operations.

b. Making restraints adjustable to account for variations in crew anthropometry or range of motion.]

8.5.2 Restraint and Mobility Aid Standardization

[V2 8038] Restraints and mobility aids **shall** be standardized, clearly distinguishable, and located to aid crewmembers in starting or stopping movement, changing direction or speed, or translating equipment.

[Rationale: Restraints and mobility aids such as handholds and foot restraints allow crewmembers to efficiently move from one location to another in microgravity, as well as reduce the likelihood of inadvertent collision into hardware that may cause damage to the vehicle or injury to the crew. Without predefined restraints and mobility aids, personnel may use available equipment that may be damaged from induced loads. By standardization of the restraints and mobility aids, reduction in crew training can occur, and the aids can be easily identified when

translating inside or outside the spacecraft. Commonality among visual cues is important so that crews can easily distinguish intended restraints and/or mobility aids from equipment or structures that may be damaged by the application of crew-induced loads. During emergencies, crews need to be able to quickly discern restraints and/or mobility aids from the surrounding structures. Visual cues such as color coding may aid in this function.]

8.5.3 Mobility Aid for Assisted Ingress and Egress

[V2 8040] Mobility aids **shall** be provided for the assisted ingress and egress of suited or unsuited crewmembers.

[Rationale: Crewmembers needing assistance (including suited crew, in either pressurized or unpressurized suits, or unsuited crew) may be unable to ingress or egress spacecraft and may also be in a constrained position that requires assistance from another person. Moving the crew may include ingress from EVA or ingress/egress to/from another spacecraft from EVA or any vehicle or module to which a spacecraft is docked. Mobility aids are employed to protect crewmembers from a fall when descent from height is necessary to reach surface for EVAs. Assisting crew may need mobility aids not only for translating but also for stabilization during the translation of the incapacitated crewmember. Note that the term "mobility aids" is not intended to indicate a specific design solution; rather, the intent is to ensure that physical design of vehicles accommodate operations such as those described here. Mobility aids may refer to specially designed hardware (e.g., handholds) or the use of existing features of the system for mobility (e.g., a handle on a hatch), in which case additional testing and verification may be required.]

8.5.4 Unassisted Ingress, Egress, and Escape Mobility Aids

[V2 8041] Mobility aids **shall** be provided for ingress, egress, and escape of crewmembers without assistance from other crew or ground personnel.

[Rationale: In off-nominal situations, the crew may need to ingress, egress, or escape unassisted while suited or unsuited. Because a suited crewmember has limited maneuverability, mobility aids allow a more safe and efficient ingress and egress of the vehicle and escape from the pad. Mobility aids are employed to protect crewmembers from a fall when descent from height is necessary to reach surface for EVAs. Note that the term "mobility aids" is not intended to indicate a specific design solution; rather, the intent is to ensure that physical design of vehicles accommodate operations such as those described here. Mobility aids may refer to specially designed hardware (e.g., handholds) or the use of existing features of the system for mobility (e.g., a handle on a hatch), in which case additional testing and verification may be required.]

8.5.5 Mobility Aid Provision

[V2 8042] Mobility aids **shall** be provided to support all expected suited and unsuited tasks.

[Rationale: Mobility aids must support all tasks, which may be suited or unsuited. Because of the limited maneuverability of a suited crewmember, mobility aids are required to allow crewmembers to safely and efficiently ingress and egress the vehicle in both microgravity and on the surface. Predefined mobility aids help prevent personnel from using available equipment that may be damaged from induced loads. Mobility aids are to be designed to accommodate a pressurized-suited crewmember by providing clearance, non-slip surfaces, and noncircular cross sections.

- *Microgravity operations considerations: Early experience in the Skylab program showed the problems of movement in microgravity. Stopping, starting, and changing direction all require forces that are best generated by the hands or feet. Mobility aids such as handholds and foot restraints allow crewmembers to efficiently move from one location to another in microgravity, as well as reduce the likelihood of inadvertent collision into hardware that may cause damage to the vehicle or injury to the crew. Appropriately located mobility aids make this possible. Mobility aids for microgravity suited operations must be provided along the expected translation paths of suited crewmembers at an interval that accommodates the suited crewmember's reach.*

- *Surface operations considerations: Experience in the Apollo program showed the problems of movement in partial gravity due to the lack of reaction forces which caused issues ambulating and utilizing tools that provided torque. Mobility aids will be required when ingressing and egressing a vehicle as well as to protect crewmembers from a fall when descent from height is necessary to reach surface for EVAs. Multi-purpose mobility aids could help reduce the number of items required (e.g., a surface EVA mobility aid may serve as a cart for ICR transport, provide additional lighting, and be a UHF/wifi-repeater).]*

8.6 Windows

Windows are an integral part of many aspects of spaceflight operations with respect to their location, optical properties, fields of view, and protection. The minimum critical design parameters for windows to support these operations and tasks are size, color balance, haze, transmittance, wavefront quality, reflectance, material inclusions, surface defects, ambient illumination, visual obstructions, e.g., mounting for optical hardware and cameras, internal and external contamination, the position of windows on the spacecraft, and the distance, position, and orientation of the user relative to a window.

8.6.1 Window Provisioning

[V2 8043] The system **shall** provide windows with unobstructed fields of view for expected crew operations.

[Rationale: Windows provide direct, non-electronic, through-the-hull viewing and are essential to mission safety and success, as well as to maintaining crew psychological and physical health and safety. They support crew photography (a primary on-and-off duty activity of onboard

crews), provide situational awareness of the external environment, facilitate piloting and robotic operations, and permit safe viewing through hatches. Windows also permit stellar navigation, vehicle anomaly detection and inspection, and environmental and scientific observations. Windows do not have the failure modes associated with cameras and display systems that may not be operable during emergencies when most needed. The following hardware is not considered an obstruction to the window field of view: (1) hardware designed and intended to protect and cover windows; (2) hardware used in conjunction with piloting (i.e., Head's Up Display (HUD), Crew Optical Alignment System (COAS), or other similar equipment); (3) the outer mold line and hull structure of the vehicle, other windows, and window mullions; and (4) instrumentation applied within 13 mm (0.5 in) of the perimeter of the viewing area.]

8.6.2 Window Optical Properties

[V2 8045] System windows **shall** have optical properties commensurate with crew task needs.

[Rationale: System windows are required to have the optical properties necessary to prevent degradation of visual acuity and optical performance. JSC-66320, Optical Property Requirements for Glasses, Ceramics, and Plastics in Spacecraft Window Systems, specifies optical properties for different types of system windows according to their associated tasks (the uses to which they will be put). These optical properties provide system windows with the minimal optical performance necessary to support those tasks and permit the retrieval of imagery through windows so that the retrieved images are not blurred, degraded, or distorted. This requirement applies to all types of windows provided by the system.]

8.6.3 Window Light Blocking

[V2 8049] Each system window **shall** provide a means to prevent external light from entering the crew compartment, such that the interior light level can be reduced to 2.0 lux at 0.5 m (20 in) from each window.

[Rationale: External illumination can interfere with internal spacecraft operations such as crew sleep and onboard still and motion imaging, particularly if the illumination causes glare. Shades and shutters block external illumination from entering the habitable volume through windows. This requirement applies to all types of windows provided by the system.]

8.6.4 Window Accessory Replacement/Operation without Tools

[V2 8050] System window accessories designed for routine use **shall** be operable by one crewmember and be removable or replaceable without the use of tools.

[Rationale: System window accessories such as window covers, shades, and filters are to be designed to be easily installed and removed using their attachment features without additional tools. The ability to remove, open, replace, or close window accessories efficiently ensures proper use of the hardware and appropriate protection for the windows and the crew. This requirement applies to all types of windows provided by the system.]

8.7 Lighting

Lighting affects a crew's visual ability, health, and safety. This section defines requirements for adequate interior and exterior lighting, prevention of distractive lighting, compatibility of lighting with sleep cycles, and informative lighting. Exterior operations and environments such as EVAs and extraterrestrial surfaces pose unique challenges to lighting solutions. The overall lighting environment cannot be controlled to the extent that it can inside a vehicle. The presence (and angle) or absence of the Sun must also be taken into consideration.

Note: The interrelationship of task illumination, chromaticity, color fidelity, and circadian requirements are linked together and require developments of these requirements together.

8.7.1 Illumination Levels

[V2 8051] For interior architectures and exterior operations that do not include the presence of orbital sunlight, the system **shall** provide illumination levels to support the range of expected crew tasks, at minimum, per Table 8.7-1—Illuminance Levels, that accommodate both human observers and remote camera systems.

[Rationale: A wide range of crew tasks is expected to be performed inside and outside the vehicle over the course of a mission. The required lighting levels vary, depending on the task being performed. For instance, cabin reconfiguration after orbit insertion may require simultaneous reading of labels and checklists, crew translation, mechanical assembly, and manual control at a variety of vehicle locations, each of which requires sufficient lighting without blockage from crew and equipment in transit. Similarly, rendezvous and proximity operations may require general cabin darkening for out-the-window viewing but sufficient lighting for crew translation and manual control. A single type of lighting at a single illumination level is insufficient to support all tasks; therefore, both general and task illumination are necessary. Illumination for exterior tasks, not related to translation, and associated with an exterior environment where sunlit surfaces are not within the field of view must consider a task analysis that factors in the surrounding architecture, tasks, and near, mid, and far field targets within the field of view, as competing targets may impact illumination requirement to ensure all required targets, within the field of view are within 2 orders of magnitude for surface luminance. Extraterrestrial lighting considerations, such as surface illumination and reflection, are to be addressed. These vary depending on the extraterrestrial body selected for the mission, as well as the location on that extraterrestrial body.]

Table 8.7-1—Illuminance Levels

Lighting Intensity Level	Lux	NOTE
Translation & Stowage	>= 108	5
General Horizontal Ambient Lighting	>= 350	1, 5
General Vertical Ambient Lighting	>= 200	2, 5
Medical/Technical/Maintenance/Repair/PhotoTV Lighting	>= 750	3, 5
Crew Sleep	<=0.02	4,5

Notes:
1. *Analysis of the architecture, micro-gravity tasks, and neutral body posture, shall determine a horizontal plan (elevation) for each unique habitat volume that best describes the location of the crew's hands. The General Horizontal Ambient Lighting intensity shall be maintained within +/- 1ft (30cm) vertical height from the designated horizontal plane. Sensor orientation is pointed up (normal) towards the ceiling from the horizontal plane.*
2. *Analysis of the architecture, micro-gravity tasks, neutral body posture, and critical panel locations, shall determine a center volume vertical plane and side-wall vertical plane that best describes the location of crew's hands or controls within reach of an un-restrained crewmember. The General Vertical Ambient Lighting intensity shall be maintained within the area of the designated vertical plane. Sensor orientation is pointed normal from the vertical plane (towards observer).*
3. *Analysis of location(s) where these tasks are to be performed (permanent/fixed location or temporary) shall determine surface size and orientation for the task. The Medical/Technical/Maintenance/Repair/PhotoTV Lighting intensity shall be maintained within the designated areas. Sensor orientation is pointed normal from the surface of the plane towards the observer.*
4. *Analysis of crew sleep restraints, locations, and micro-gravity impacts shall determine a surface area describing the average eye-point location for crew-sleep. The Crew Sleep intensity shall be maintained within +/- 6 inches from the normal vector of the eye-point plane. Sensor orientation is pointed normal from the surface away from the eyes/crew member.*
5. *Area measurements will have a deviation from an average because of uneven light distribution. For each applicable illumination requirement, the stated light level shall be the "average" for the points representing the area, with a uniformity (average/minimum) ratio, no greater than 3:1 between points. The number of points to be measured describes the perimeter of the measurement and the surface area of the measurement. The distance between consecutive points within a measurement area does not exceed 1ft (30cm).*

8.7.2 Environmental Lighting Attenuation

[V2 8103] The integrated system architecture **shall** provide countermeasures to attenuate environmental lighting and complement existing active lighting architecture.

[Rationale: For external operational conditions or internal operations via a window where tasks are to be performed under unchanging direct illumination of the Sun for a duration that impacts mission safety or success, interior countermeasures, exterior support systems, system components, and/or architectures for crewed extravehicular activity (EVA) and extravehicular robotics (EVR) need to provide passive (nonpowered architectural solutions)- or active (powered illumination sources) countermeasures for the attenuation of or diffuse scatter of collimated light, that creates performance issues due to high contrast within the critical area of observation. For external operations performed without direct sunlight, without indirect sunlight reflected from Earth, or without indirect sunlight reflected from the Moon, passive countermeasures from fixed architectural and portable surfaces are considered part of the integrated lighting solution when the primary light source is a lamp or system of lamps. Lighting analysis and optimization tasks consider how surface reflectance properties interact with the system architecture used to enhance the performance of the artificial lighting system. Environmental lighting can include sunlight, glare, reflection from lunar/planetary/vehicle surfaces, etc. Countermeasures can range from crewmember-worn PPE such as sunglasses or visors, to fixtures such as diffuser screens or reflecting panels. Exterior vehicle materials and

colors can be chosen based on their reflective properties. They may be portable or considered as part of the integrated permanent worksite architecture.]

8.7.3 Task-Specific Exterior Lighting for Operational Areas Partially or Fully Lit by Sunlight

[V2 8104] For operational areas that include shadowed areas and areas illuminated by the Sun and celestial bodies, the system **shall** provide passive and/or active solutions that reduce the contrast within shadowed areas of worksites/tasks to within 2 orders of magnitude of the predicted maximum surface luminance of objects, that accommodate both human observers and remote camera systems.

[Rationale: During operations performed under unchanging direct illumination of the Sun, exterior support systems, system components, and architectures for crewed extravehicular activity (EVA) and extravehicular robotics (EVR) must provide active lighting support solutions that decrease the contrast within worksites. Collimated sunlight creates a high contrast operational environment due to the creation of shadows from the "fixed" surrounding architectures and mobile "operators". This contrast between illuminated areas and shadowed areas can impact performance and safety. Contrast can be reduced by increasing the luminance (candela/m2) using active powered illumination sources, or by decreasing the maximum surface luminance of objects using non-powered passive architectural solutions. The luminance range of the visual field(s) of the operation dictates the support requirements for supplemental systems to bring the luminance range within a usable condition for the human observer and for remote monitoring technologies. For external operational conditions where operations are to be performed without direct sunlight, without indirect sunlight reflected from Earth from low earth orbit, or without indirect sunlight reflected from the Moon from lunar orbit, the integrated lighting solution provides surface illuminance with the same required target range as interior lighting systems.]

8.7.4 Navigation and Wayfinding (Exterior)

[V2 8105] The system **shall** provide luminous powered and passive indicators that assist with proximity, navigation, and object recognition for validation of targets critical to the surface operation.

[Rationale: On an unfamiliar extraterrestrial surface, navigation can be difficult. On the Lunar surface, for example, the horizon is less than 2.5 km from a human observer, limiting line-of-sight. Depending on the position of the Sun, long shadows can present further challenges. These wayfinding markers must have features that distinguish them from the background environment. Capabilities may include bright lights, strobing, and/or alternating colors that can help crewmembers easily locate the markers to orient themselves. This function may also be provided by other means such as global positioning systems (GPS) and/or communication structures (i.e., towers, vehicles) and tracking.]

8.7.5 Emergency Lighting

[V2 8053] The system **shall** provide emergency lighting (interior and exterior) to maintain visibility in the event of a general power failure.

[Rationale: Emergency lighting is a part of the overall lighting system for all vehicles and surface operations. It allows for crew egress/translation and/or operational recovery in the event of a general power failure. The emergency lighting system is to be automatically activated to allow operators and other occupants of a vehicle to move to a safe location and allow efficient transit between any inhabited location and designated safe haven(s). Efficient transit includes appropriate orientation with respect to doorways and hatches, as well as obstacle avoidance along the egress path.]

8.7.6 White Lighting Chromaticity

[V2 8059] Interior and exterior lighting intended for operational environments requiring human/camera color vision **shall** have a chromaticity that falls within the chromaticity gamut for white light for the Correlated Color Temperature (CCT) range of 2700 K to 6500 K as defined by ANSI C78-377, Electric Lamps—Specifications for the Chromaticity of Solid-State Lighting Products.

[Rationale: The ability to make variable customized lighting spectra adds risk that an implementer will come up with a light that meets some color constraints but fails to create an environment that appears white or will create one in which cameras have trouble operating. ANSI C78-377 (see NEMA C78.377) forces the definition of white to be a color gamut along the blackbody locus of the International Commission on Illumination (CIE) 1931 chromaticity chart. For variable CCT systems, it is important that humans and cameras within that environment see color correctly and interpret the light as white light anywhere along the color range of white light as defined by ANSI C78-377. Exceptions to this requirement include conditions that do not require color vision such as window operations and sleep environment, as determined by a task analysis. This technical requirement is only for white light and does not apply to the definition of chromaticity of lamps intended for indication purposes (white strobes, white indicators, green, red, etc., lights).]

8.7.7 White Lighting Color Accuracy

[V2 8060] Interior and exterior lighting intended for human operational environments requiring photopic vision accuracy **shall** have a score of 90 ±10 on a color fidelity metric that is appropriate for the utilized lighting technology, as designated by the Color Fidelity Metric (Rf) defined by IES TM-30, Method for Evaluating Light Sources Color Rendition methodology.

[Rationale: Accurate representation of the colored environment impacts several areas of concern for human performance and behavior, including critical color matching tasks (e.g., matching litmus strips to cue cards) and the representation of skin tone and biological material (e.g., for health diagnostics). Rapid advancements in modern lighting technology such as solid-

state lighting require careful consideration of the proper color fidelity metric selection for the evaluation of color rendition properties of a light source. Color Rendering Index (CIE CRI Ra) is the first established color fidelity metric; it is widely used but it is an improper metric for sources below CCT of 5000 K as well as sources with peaked spectra such as solid-state technology. Color Quality Scale (CQS) improves upon the methodology of CRI to more accurately describe color hue and saturation shifts. For a complete suite of color rendition metrics, the IES TM-30 method is recommended. TM-30 provides a color fidelity metric (Rf) that is analogous to CRI Ra but more accurate, a color gamut index (Rg) to describe color saturation, and a color vector graphic for visualization of hue and saturation changes with respect to a reference source. IES TM-30 has an extensive toolset for evaluation of the ability of a lamp to properly render colored materials within an environment. This toolset is advanced from the Color Quality Scale and provides a means to evaluate the performance of a lighting system with any material, given its spectral reflectance, allowing for tailoring for program-specific critical colored surfaces. It is highly recommended that this tool be included in any lighting performance specification. Situations to which this requirement applies are determined by a task analysis. This technical requirement is only for white light and does not apply to the definition of chromaticity of lamps intended for indication purposes (white strobes, white indicators, green, red, etc., lights).]

8.7.8 Physiological Effects of Light (Circadian Entrainment)

[V2 8055] The system **shall** provide the levels of light to support the physiological effects of light in accordance with Table 8.7-2—Physiological Lighting Specifications.

[Rationale: Light is both a stimulant and the most effective signal for entraining and resetting the circadian clock. The magnitude of these effects depends primarily on the intensity, spectrum, timing and duration of light. Lighting Systems must provide proper light to promote alertness during wake and work hours, promote sleepiness during the 'pre-sleep' time, and promote or avoid circadian resetting when required. Failure to provide adequate lighting during wake will lead to suboptimal alertness and performance. Failure to provide appropriate lighting during pre-sleep will lead to prolonged sleep latency, reduced sleep duration and reduced sleep quality, and suppression of the pineal 'darkness' hormone melatonin. Failure to provide an adequate 24-hour light-dark cycle (or a 24-hour and 40-minute cycle for Mars missions) will lead to misalignment between the circadian clock and the rhythms the clock controls including, but not limited to, sleep, performance, mood, metabolism, endocrine function, immune function, reproductive function and glucose and lipid regulation. It is important to note that in the absence of an appropriate light signal, the circadian rhythm will IMMEDIATELY begin to mis-align, which is why it is necessary to require lighting sufficient for entrainment on short-duration missions. Failure to provide appropriate circadian resetting in response to a shift schedule will also lead to circadian misalignment.]

Table 8.7-2—Physiological Lighting Specifications

Lighting Levels at Cornea	Melanopic EDI Lux	Melanopic DER	Peak Wavelength	NOTE
General Ambient Lighting	≥ 250	≥ 0.7	480 ± 10nm (blue-enriched)	1, 2
Crew Pre-Sleep	8 +/- 2	≤ 0.3	≥ 550nm (blue-depleted)	1, 3

Notes:
1. *Melanopic EDI is measured at the cornea in the vertical plane. Both EDI and DER thresholds for each lighting condition must be met.*
2. *During all waking hours, the white light must be 'blue-enriched' to maintain alertness and entrainment of the circadian pacemaker to a 24-hour day and facilitate schedule shifting when required.*
3. *During scheduled pre-sleep, the white light must be 'blue-depleted' to reduce alertness and prepare the brain for sleep.*
4. *Melanopic Equivalent Daylight Illuminance (EDI, in melanopic lux) and melanopic Daylight Equivalent Ratio (DER, no units)* ***shall*** *be calculated according to the most recent version of the International Commission on Illumination (CIE) International Standard: CIE S 026:2018. System for Metrology of Optical Radiation for ipRGCInfluenced Responses to Light. CIE, Vienna (DOI: 10.25039/S026.2018)*
5. *CIE Position Statement on Non-Visual Effects of Light. 2019 https://cie.co.at/files/CIE%20Position%20Statement%20-%20Proper%20Light%20at%20the%20Proper%20Time%20(2019)_0.pdf*
6. *Brown, T.; Brainard, G.; Cajochen, C.; Czeisler, C.; Hanifin, J.; Lockley, S.; Lucas, R.; Munch, M.; O'Hagan, J.; Peirson, S.; Price, L.; Roenneberg, T.; Schlangen, L.; Skene, D.; Spitschan, M.; Vetter, C.; Zee, P.; Wright Jr., K. Recommendations for Healthy Daytime, Evening, and Night-Time Indoor Light Exposure. Preprints 2020, 2020120037 (doi: 10.20944/preprints202012.0037.v1).*

8.7.9 Lighting Controls

[V2 8056] Lighting systems **shall** have on-off controls.

[Rationale: Controls for turning lighting on and off within each module allow crewmembers to see the effect of changes to lighting controls without changing their location. Easy access to the controls is necessary. Light sources are to be capable of being turned completely off and returned to on. This control allows for conservation of lamps that would otherwise be noncontributory due to blockage by configuration of equipment, crew gear, payloads, stowage containers, deployed sun shields, etc.]

8.7.10 Lighting Adjustability

[V2 8057] Interior and exterior lights **shall** be adjustable (dimmable).

[Rationale: Interior and exterior lighting is to be adjustable as needed by the crew to accommodate task-specific lighting needs.]

8.7.11 Glare Prevention

[V2 8058] The integrated system architecture including surrounding surfaces, support equipment, visualization tools, and supporting lighting systems **shall** work in conjunction to minimize visibility and eye-safety impacts from direct and indirect glare.

[Rationale: Glare must first be eliminated though proper consideration and arrangement of the spacecraft internal system architectural environment, including the lighting system, window design, architectural surface treatments, and backlit displays. In situations where this perfect

arrangement is not possible, mitigating measures such as lighting source baffles, window shades, and computer monitor glare shields can be used. Eye discomfort can occur, and visual performance can be negatively affected by glare. If a light source within the observer's field of view provides much more luminance than its surroundings (higher range of contrast) and occupies a significant portion of the field of view, it may act as a direct glare source. If the reflection of a light source from a surface within the field of view provides an area whose luminance greatly exceeds that of its surroundings, it may act as a reflected (indirect) glare source. The types of tasks expected to be performed are to be considered, as well as the location where the tasks occur, whether they are internal or external to the vehicle, and whether they are on or off a planetary surface. For applications where a human is a primary observer and dominant surface features, for the field of view of the operation, are less than 50% reflective, or if the primary surfaces have highly specular surface properties, the integrated lighting solution are to include countermeasures for direct glare (to reduce luminance) from reflected light from specular objects, while adjusting surface contrast ratio (max luminance of adjusted visual field/luminance of critical task surface) of the visual field to meet contrast performance objectives, while maintaining acceptable thresholds for color vision and visual acuity. Eye safety impacts and limits are further discussed in [V2 6117] Artificial Lighting Exposure.]

8.7.12 Extraterrestrial Surface Transport Vehicle (ESTV) Dashboard and Control Lighting

[V2 8106] The system **shall** provide active lighting and attenuation of solar light for manual controls (e.g., unpressurized surface transport vehicle joystick controls, switches and dashboard) and display screens to be visible in all potential natural light levels, including complete darkness.

[Rationale: ESTV activities will likely go between areas of intense natural light and a complete absence of natural light, often near-instantaneously. Proper lighting of manual controls (joysticks, switches etc.) and display screens must be visible under all conditions to ensure safe and effective control of the ESTV. Care must also be taken that dashboard lighting does not cause annoyances, such as reflections on ESTV windows. Factors that are to be considered in meeting this requirement include:

a. Attenuation of ambient light that could obscure legibility of the instrument panel.

b. Attenuation (or blocking) of glare sources within the field of view in the direction of travel.

c. Controls to increase or decrease the luminance (cd/m^2) of backlit displays and indicators so that the crew can adjust contrast to be within adaptation levels.

d. Surface materials that minimize reflections onto windows and displays that could obscure the field of view.

For requirements and guidance on display legibility see [V2 5051] Legibility and [V2 10048] Visual Display Parameters.]

9. HARDWARE AND EQUIPMENT

This section provides requirements applicable to the design of hardware and equipment. Requirements in this section apply to all hardware and equipment with which the crew interfaces—from large and complex systems such as ISS racks, to small items such as tools, drawers, closures, restraints, mobility aids, fasteners, connectors, clothing, and crew personal equipment. Hazard minimization is accomplished through hardware design, and design of interior components which crew may encounter, through nominal mission activities, including maintenance operations, and anticipated off-nominal events.

Equipment refers to items such as tools used to accomplish a task or activity. Equipment is a type of hardware, and therefore this term is sometimes used interchangeably with hardware.

Hardware refers to individual components of equipment, including but not limited to fasteners, panels, plumbing, switches, switch guards, and wiring. This term is sometimes used interchangeably with equipment.

9.1 Standardization

9.1.1 Crew Interface Commonality

[V2 9001] Hardware and equipment performing similar functions **shall** have commonality of crew interfaces.

[Rationale: The intent of this requirement is to ensure commonality and consistency within a given human spaceflight program. This facilitates learning and minimizes crew error.]

9.1.2 Differentiation

[V2 9002] Hardware and equipment that have the same or similar form but different functions **shall** be readily identifiable, distinguishable, and not be physically interchangeable.

[Rationale: The intent of this requirement is to avoid potential confusion crewmembers may experience that can lead to errors when items with similar form are not readily identifiable or physically distinguishable.]

9.1.3 Routine Operation

[V2 9003] Worksites **shall** be designed to provide rapid access to needed tools and equipment for routine/nominal operations.

[Rationale: Good design of systems and equipment can reduce the amount of time to perform many routine tasks, e.g., food preparation, maintenance, and inventory management. Having to retrieve, use, and stow tools for the routine/nominal operation of systems, hardware, and

equipment can be especially cumbersome and burdensome for routine tasks. The ability to perform operations with promptness helps ensure proper use.]

9.2 Training

9.2.1 Training Minimization

[V2 9004] Hardware and equipment with which crew interact **shall** minimize the time required for training.

[Rationale: Generally, designers can minimize training by following requirements dictated in this NASA Technical Standard under section 9.1 Standardization, and Section 10 Crew Interfaces. However, a specific system may have characteristics that could minimize training requirements. For example, an upgrade in technology of an existing system could maintain the same interface. This could be defined in system requirements and would minimize the need for additional training.]

9.2.2 In-Mission Training

[V2 9110] In-mission training/refreshers, including using tools and test equipment required for maintenance, **shall** be provided to ensure crew proficiency in performing maintenance activities.

[Rationale: Repairs are designed to be as simple as possible. However, because of the length of time between crew training and missions, providing in-mission training/refreshers allows for just-in-time training. Videos and/or augmented reality are examples of training tools that may be provided.]

9.3 Hazard Minimization

9.3.1 Mechanical Hazard Minimization

9.3.1.1 Design for Crew Safety

[V2 9101] The system **shall** be designed to minimize physical hazards to the crew.

[Rationale: Physical hazards to the crew, such as moving mechanical parts, entrapment, potential energy, loose item projectiles, sharp edges, pinch points, equipment handling, fluid/gas release, etc., are to be mitigated throughout the system design. Safety hazard analyses are to be performed to identify all known hazards to crew and corresponding hazard controls. Hazards can be avoided by designing out the hazard, controlled by the use of safety devices, or mitigated by providing warnings, or through procedures and training. These are arranged in descending order of preference; designing out the hazard is the most preferred, while relying on procedures or training is the least preferred.]

9.3.1.2 Mechanical Hazard

[V2 9005] Systems, hardware, and equipment **shall** protect the crew from moving parts that may cause injury to the crew.

[Rationale: Known mechanical hazard sources can be defined in a requirement. Consistently moving equipment is easy to identify and guard. Infrequent or unpredictable movement may be a less obvious hazard. If possible, system requirements are to identify potential sources of unpredictable or infrequent movement and spell out specific guarding requirements for these systems.]

9.3.1.3 Entrapment

[V2 9006] Systems, hardware, and equipment **shall** protect the crew from entrapment (tangles, snags, catches, etc.).

[Rationale: This applies to items with which the crew will come into direct contact. Entrapment can occur in places where loose cables or equipment items block passageways or where crewmembers purposely fasten motion restraints (seat belts and shoulder harnesses, foot restraints, tethers, etc.). Entrapment can also occur from protrusions or openings that snag body parts or personal equipment. For example, if holes are small, then fingers may be entrapped. Larger holes, on the other hand, allow free movement. Crewmembers are likely to be under time-critical conditions when they need to evacuate or return to safety. If possible, requirements are to focus on those situations.]

9.3.1.4 Potential Energy

[V2 9007] Hardware and equipment **shall not** release stored potential energy in a manner that causes injury to the crew.

[Rationale: Requirements are to identify all known sources of stored potential energy. As with all hazards, this can be mitigated by designing out the hazard, the use of safety devices, providing warnings, or through procedures and training. These mitigations are arranged in descending order of preference: designing out the hazard is the most preferred, while relying on procedures or training is the least preferred.]

9.3.1.5 Protection from Projectiles and Structural Collapse

[V2 9008] Hardware mounting and habitat enclosures **shall** be configured such that the crew is protected from projectiles and structural collapse in the event of sudden changes in acceleration or collisions.

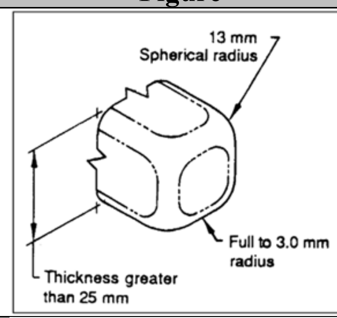
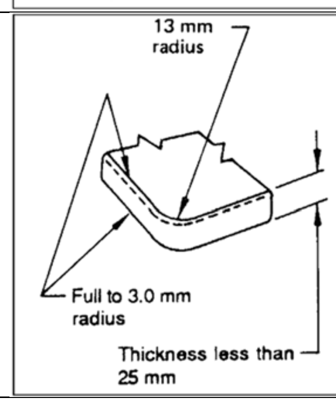
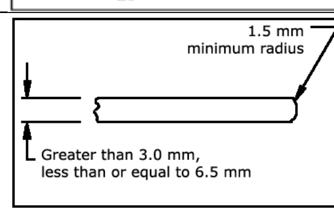
[Rationale: Chances for crew survivability in otherwise catastrophic conditions can be greatly increased by attention (early in the design process) to structure and mounting designs such that the crew habitable volume remains intact and free of secondary projectiles.]

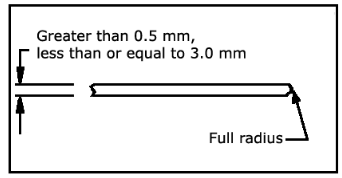
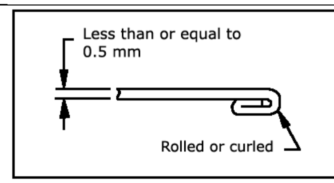
9.3.1.6 Sharp Corners and Edges – Fixed

[V2 9009] Corners and edges of fixed and handheld equipment to which the bare skin of the crew could be exposed **shall** be rounded as specified in Table 9.3-1—Corners and Edges.

[Rationale: Sharp corners and edges in passageways, maintenance areas, stowage compartments, or workstations present hazardous conditions and are to be avoided. Also, hand-held items such as tools present a hazard to the crew. In addition to potential hazards from IVA exposure, EVA exposure to sharp surfaces could damage suit integrity. This requirement applies to bare skin. Gloves and clothing may protect skin; however, some clothing or equipment items may be more vulnerable to tears and cuts. The crew may be exposed to items manufactured by a variety of companies, and this requirement is to be reflected in requirements for all of them.]

Table 9.3-1—Corners and Edges

Material Thickness (t)	Minimum Corner Radius	Minimum Edge Radius	Figure
t > 25 mm (t > 1 in)	13 mm (0.5 in (spherical))	3.0 mm (0.120 in)	
6.5 mm ≤ t≤25 mm (0.25 in < t < 1 in)	13 mm (0.5 in)	3.0 mm (0.125 in)	
3.0 mm ≤ t < 6.5 mm (0.125 in < t < 0.25 in)	6.5 mm (0.26 in)	1.5 mm (0.06 in)	

Material Thickness (t)	Minimum Corner Radius	Minimum Edge Radius	Figure
0.5 mm ≤ t < 3.0 mm (0.02 in < t < 0.125 in)	6.5 mm (0.26 in)	Full radius	
t < 0.5 mm (t < 0.02 in)	6.5 mm (0.26 in)	Rolled, curled, or covered to 3.0 mm (0.120 in)	

9.3.1.7 Protection from Functionally Sharp Items

[V2 9010] Functionally sharp items **shall** be prevented from causing injury to the crew or damage to equipment when not in use.

[Rationale: Functionally sharp items are those that, by their function, do not meet the requirement for exposed corners and edges, e.g., syringes, scissors, and knives. These items are to be prevented from causing harm when not in nominal use. Capping sharp items is one way of doing this.]

9.3.1.8 Sharp Corners and Edges - Loose

[V2 9011] Corners and edges of loose equipment to which the crew could be exposed **shall** be rounded to radii no less than those given in Table 9.3-2—Loose Equipment Corners and Edges.

[Rationale: The force (and resulting damage) in contact with fixed items depends on the mass and speed of the crewmember. The damage from loose items, however, depends on the weight of the item. For example, a person running into a fixed clipboard will cause more damage than if the clipboard were thrown at that person. Therefore, the corners and edges of a loose item do not have to be as rounded as a fixed item. Although hand-held items are loose, they are squeezed, and forces can be high. Therefore, hand-held items are to meet the edge and corner rounding requirements of fixed items as referenced in [V2 9009] Sharp Corners and Edges–Fixed, in this NASA Technical Standard.]

Table 9.3-2—Loose Equipment Corners and Edges

Equipment Mass		Minimum Edge Radius (mm (in))	Minimum Corner Radius (mm (in))
At Least (kg (lb))	Less Than (kg (lb))		
0.0 (0.0)	0.25 (0.6)	0.3 (0.01)	0.5 (0.02)
0.25 (0.6)	0.5 (1.1)	0.8 (0.03)	1.5 (0.06)
0.5 (1.1)	3.0 (6.6)	1.5 (0.06)	3.5 (0.14)
3.0 (6.6)	15.0 (33.1)	3.5 (0.14)	7.0 (0.3)
15.0 (33.1)	--	3.5 (0.14)	13.0 (0.5)

9.3.1.9 Burrs

[V2 9012] Exposed surfaces **shall** be free of burrs.

[Rationale: Burrs are manufacturing artifacts or can occur during a mission as a result of maintenance or assembly operations. Burrs cause damage to equipment and skin. They are to be removed as a part of the manufacturing process; or, if it is likely that they will be created during a mission, a means is to be provided to eliminate crew exposure to the burrs.]

9.3.1.10 Pinch Points

[V2 9013] Pinch points **shall** be covered or otherwise prevented from causing injury to the crew.

[Rationale: Pinch points can cause injury to the crew but may exist for the nominal function of equipment, i.e., equipment panels. This may be avoided by locating pinch points out of the reach of the crew or by providing guards to eliminate the potential to cause injury.]

9.3.1.11 Equipment Handling

[V2 9016] All items designed to be carried or removed and replaced **shall** have a means for grasping, handling, and carrying while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Grasping, gripping, and moving hardware using hardware features that are not intended to be handles can damage the hardware or slip away and injure the crewmember or damage surrounding hardware. This can be prevented by designing obvious features that are intended for grasping, gripping, or moving the item. Manual Materials Handling (MMH) guidance can be used for identifying the appropriate MMH method based on equipment size, shape, weight (mass), gloved/ungloved, 1- or 2-person carry, etc. Pressurized and unpressurized suit biomechanics also needs to be considered for any tasks performed while suited as referenced in [V2 11024] Ability to Work in Suits, in this NASA Technical Standard.]

9.3.2 Temperature Exposure

The following temperature exposure requirements for bare skin [V2 9102] Skin/Tissue Damage Temperature Limits, and [V2 9103] Pain/Non-Disabling Injury Skin Temperature Limits, are summarized in Figure 9.3-1—Summary of Bare Skin Exposure Temperature Ranges, and Table 9.3-3—Summary Table of Bare Skin Exposure Temperature Ranges/Limits.

These temperatures are temperature limits for the outer layer of the skin. The calculation of the material being touched, in relation to its temperature and the contact time, will result in a skin temperature at the end of the contact period. This temperature must be compared to the values in Figure 9.3-1 to determine the need for control(s). Duration of skin contact with an object that is beyond the skin limits ensures the skin temperature is within the nominal range, may be used as *a control. Refer to tables 9.3-(3-10) for equations and sample calculations for different materials that may be used to determine the duration of skin contact. Refer to ASTM C1057-17, Standard Practice for Determination of Skin Contact Temperature from heated surfaced using a mathematical model and thermesthesiometer.*

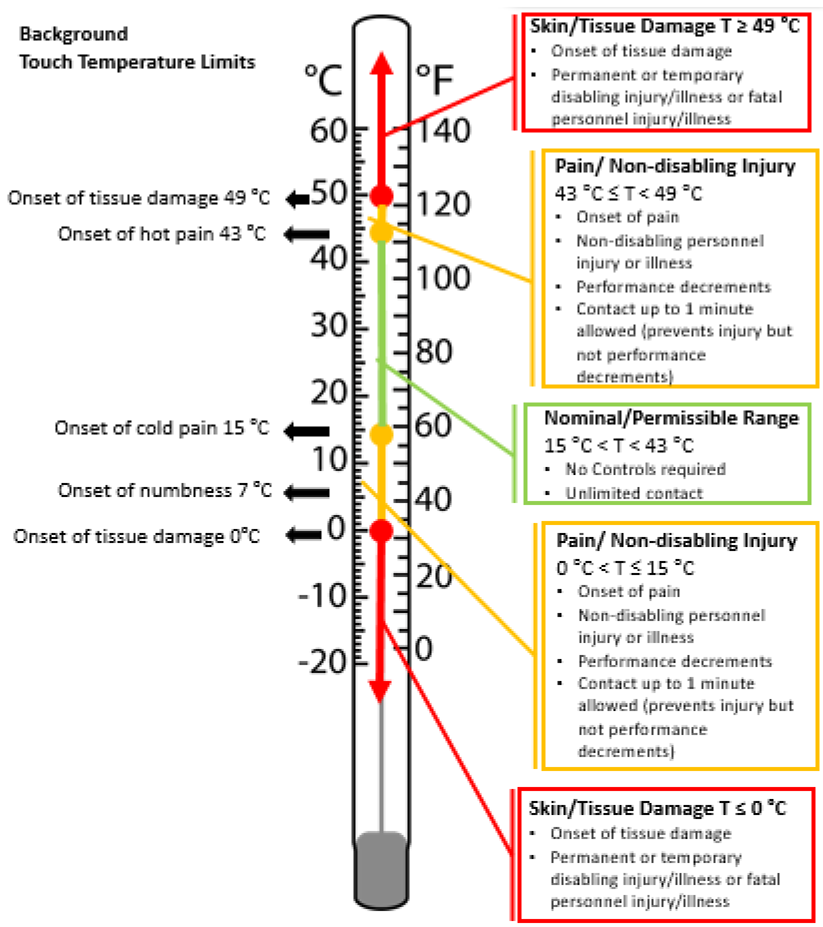


Figure 9.3-1—Summary of Bare Skin Exposure Temperature Ranges

Table 9.3-3—Summary Table of Bare Skin Exposure Temperature Ranges/Limits

Nominal Thresholds (No Controls Required, Unlimited Contact)	**Sensation/Pain** (Pain/Non-Disabling Injury/Possibly Resulting in Illness) **[V2 9103]**	**Skin/Tissue Damage** (Controls required) **[V2 9102]**
$15°C < T_{skin} < 43°C$	$43°C \leq T_{skin} < 49°C$ or $0°C < T_{skin} \leq 15°C$	$T_{skin} \geq 49°C$ or $T_{skin} \leq 0°C$

9.3.2.1 Skin/Tissue Damage Temperature Limits

[V2 9102] Any surface to which the bare skin of the crew is exposed **shall not** cause skin temperature to exceed the injury limits in Table 9.3-4—Skin Temperature Injury Limits.

[Rationale: Skin Temperature Injury Limits are defined as any condition that may cause a permanent or temporary disabling injury/illness or fatal personnel injury/illness. For touch temperature, this condition was considered when tissue damage may be experienced. The following references were utilized to determine the limits: Hot: Greene, L.C., et al. (1958) on human tolerance to heat pain showed that the pain threshold is reached at 43.7ºC (110.7ºF) skin temperature. Lloyd-Smith, D.L., and Mendelssohn, K. (1948) found the pain threshold to be 44.6ºC (112.3ºF). Defrin, et al. (2006), found the pain threshold to be between 43-46ºC (109-115ºF). Damage to porcine skin was determined to be at 49ºC (120.2ºF) (Moritz, et al., 1947). Hand dysfunction and the associated safety risk during occupational practices in the cold increases with decreasing skin temperature. Onset of cold pain has been reported to occur between 23°C (73.4ºF) and 14°C (57.2ºF) during cold contact (Havenith, et al., 1992). A marked deterioration in tactile discrimination occurs at finger skin temperatures <8ºC (46.4ºF) with numbness found in one-third of subjects at 7°C (44.6ºF) (Morton and Provins, 1960). Risk of frostbite occurs at 0 °C (32ºF) (Havenith, et al., 1992.). Time of skin exposure may be used as a control; this will depend on material and contact area and may be calculated using thermal models.]

Table 9.3-4—Skin Temperature Injury Limits

Tissue Damage	Temperature Threshold Limit
High Temperature Limit	≥ 49ºC
Low Temperature Limit	≤ 0ºC

9.3.2.2 Pain/Non-Disabling Injury Skin Temperature Limits

[V2 9103] Any surface to which the bare skin of the crew is exposed **shall not** cause skin temperature to enter the range for pain/injury in Table 9.3-5—Range for Pain/Non-Disabling Injury/Possibly Resulting in Illness.

*[Rationale: Pain/Non-Disabling Injury Skin Temperature Limits are defined as any condition which may cause pain and performance decrements. The following references were utilized to determine the limits: Hot: Greene, L.C., et al. (1958) on human tolerance to heat pain showed that the pain threshold is reached at 43.7ºC (110.7ºF) skin temperature. Lloyd-Smith, D.L., and Mendelssohn, K. (1948) found the pain threshold to be 44.6ºC (112.3ºF). Defrin, et al. (2006), found the pain threshold to be between 43-46ºC (109-115ºF). Damage to porcine skin was determined to be at 49ºC (120.2ºF) (Studies of thermal injury ii. The relative importance of time and surface temperature in the causation of cutaneous burns *A. R. Moritz M.D., and F. C. Henriques, Jr., Ph.D. [From the Department of Legal Medicine, Harvard Medical School, Boston, Mass, 1946]. Cold Temperature Limit Values For Touching Cold Surfaces with the Fingertip [Q. Geng, et al., Ann. Occup. Hyg., Vol. 50, No. 8, pp. 851–862, 2006]). Hand dysfunction and the associated safety risk during occupational practices in the cold increases*

with decreasing skin temperature. Onset of cold pain has been reported to occur between 23°C (73.4ºF) and 14°C (57.2ºF) during cold contact (Havenith, et al., 1992). A marked deterioration in tactile discrimination occurs at finger skin temperatures <8ºC (46.4ºF) with numbness found in one-third of subjects at 7°C (44.6ºF) (Morton and Provins, 1960). Risk of frostbite occurs at 0°C (32ºF) (Havenith, et al., 1992).]

Table 9.3-5—Range for Pain/Non-Disabling Injury/Possibly Resulting in Illness

Pain/Performance Decrements	Temperature Threshold Limit
High Temperature Range	$43°C \le T_{skin} < 49°C$
Low Temperature Range	$0°C < T_{skin} \le 15°C$

The following information is provided to aid designers in determining the duration of contact allowed for different materials before the skin exceeds the temperature limits.

The following tables and figures provide data and outline the methodology for determining the duration of contact time with an object, with respect to the skin temperature limits. In order to calculate the material thermal inertia, use documented thermophysical property resources. Table 9.3-6, Inverse Thermal Inertia for Commonly Used Materials, provides Inverse thermal Inertia for Commonly Used Materials. For high (43°C, 49°C) or low (0°C, 15°C) temperatures, use the subsequent figures (9.3-(2-5)) and tables (9.3-(6-10)) to determine the permissible material temperature (T_{PM}) for the expected time of contact.

Table 9.3-6—Inverse Thermal Inertia for Commonly Used Materials

Material	Inverse Thermal Inertia* $x = \frac{1}{\sqrt{k\rho c}}$ ($m^2\ s^{0.5}\ K/J$)
Aluminum 6061 T-6	5.24×10^{-5}
316 Stainless Steel	1.420×10^{-4}
Glass	6.61×10^{-4}
Teflon(R)	1.430×10^{-3}
Nylon Hook Velcro	1.400×10^{-2}

**the unit of measure for thermal inertia is ($m^2\ s^{0.5}\ K/J$)*

Determining Material Temperature and Duration of Contact for 49°C

To determine the catastrophic temperature (T_{cat}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation $T_{cat} = \frac{a}{\sqrt{(k\rho c)}} + b$ and constants from Table 9.3-7—High Temperature Constants: 49°C, to perform the appropriate calculations;

or

Utilize the calculated and graphed values in Figure 9.3-2—High T_{cat} for Incidental and Intentional (Planned) Contact for 49°C.

Table 9.3-7—High Temperature Constants: 49°C

time (s)	a	b
1	23,600	68.2
10	24,400	54.3
30	24,400	51.9
60	24,400	51.0
∞	24,400	49.6

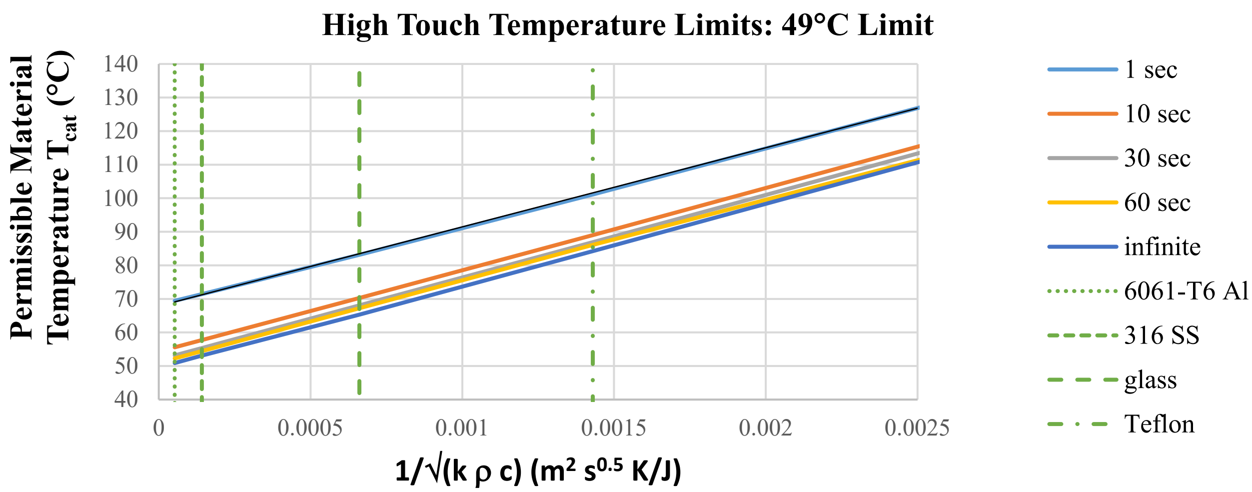


Figure 9.3-2—High Temperature T_{cat} for Incidental and Intentional (Planned) Contact (49°C)

Determining Material Temperature and Duration of Contact for 43°C

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation $T_{PM} = \frac{a}{\sqrt{(k\rho c)}} + b$ *and constants from Table 9.3-8—High Temperature Constants: 43°C, to perform the appropriate calculations;*

or

Utilize the calculated and graphed values in Figure 9.3-3—High T_{PM} for Incidental and Intentional (Planned) Contact for 43°C.

Table 9.3-8—High Temperature Constants: 43°C

time (s)	a	b
1	15,500	55.2
10	15,500	46.4
30	15,500	44.8
60	15,500	44.3
∞	15,500	43.4

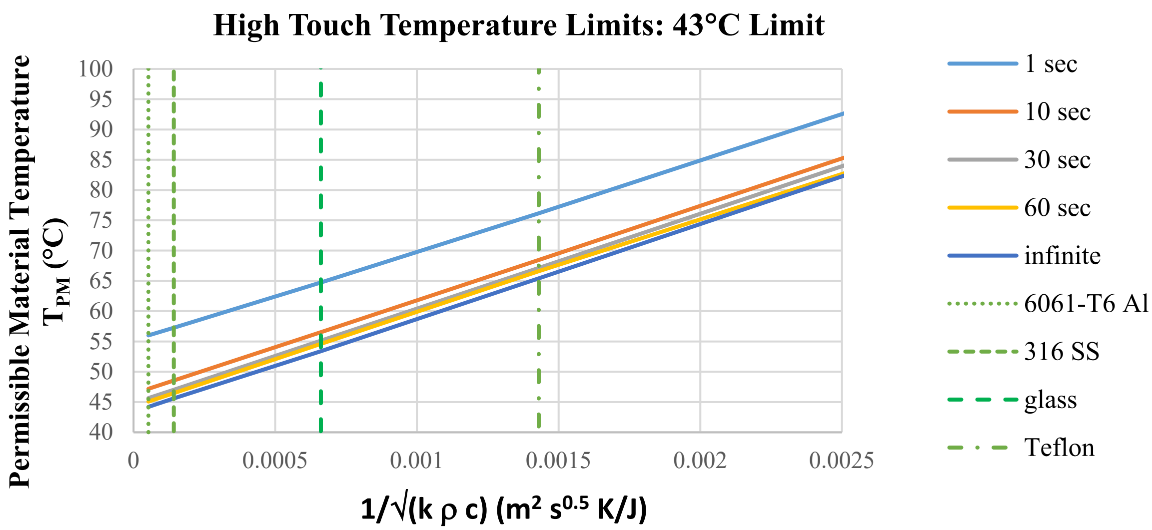


Figure 9.3-3—High T_{PM} for Incidental and Intentional (Planned) Contact (43°C)

Determining Material Temperature and Duration of Contact for 15°C

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation $T_{PM} = \frac{a}{\sqrt{(k\rho c)}} + b$ *and constants from Table 9.3-9—Low Temperature Constants: 15°C, to perform the appropriate calculations;*

or

Utilize the calculated and graphed values in Figure 9.3-4—Low T_{PM} for Incidental and Intentional (Planned) Contact for 15°C.

Table 9.3-9—Low Temperature Constants: 15°C

time (s)	a	b
1s for $(k\rho c)^{0.5} < 2.324 \times 10^{-4}$	-48,600	0
1s for $(k\rho c)^{0.5} \geq 2.324 \times 10^{-4}$	-23,800	-5.77
10	-22,700	15
30	-16,400	15
∞	-11,700	15

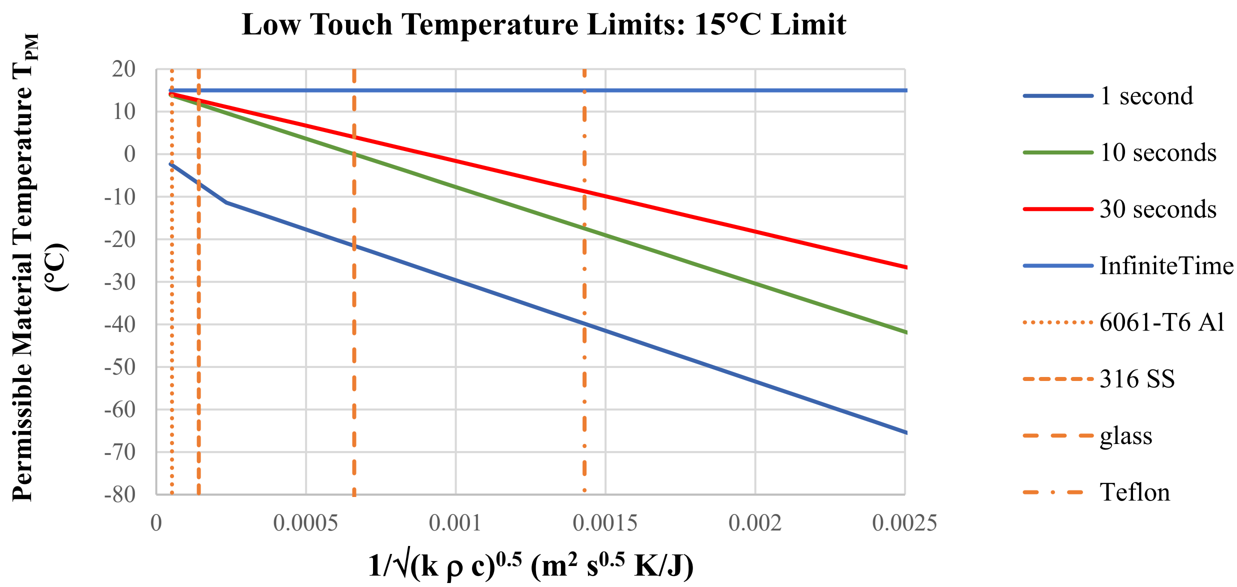


Figure 9.3-4—Low T_{PM} for Incidental and Intentional (Planned) Contact (15°C)

Determining Material Temperature and Duration of Contact for 0°C

To determine the catastrophic temperature (T_{cat}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

Use either the equation $T_{cat} = \frac{a}{\sqrt{(k\rho c)}} + b$ and constants from Table 9.3-10—Low Temperature Constants: 0°C, to perform the appropriate calculations;

or

Utilize the calculated and graphed values in Figure 9.3-5—Low T_{cat} for Incidental and Intentional (Planned) Contact for 0°C.

Table 9.3-10—Low Temperature Constants: 0°C

time (s)	a	b
1	-48,600	0
∞	-19,400	0

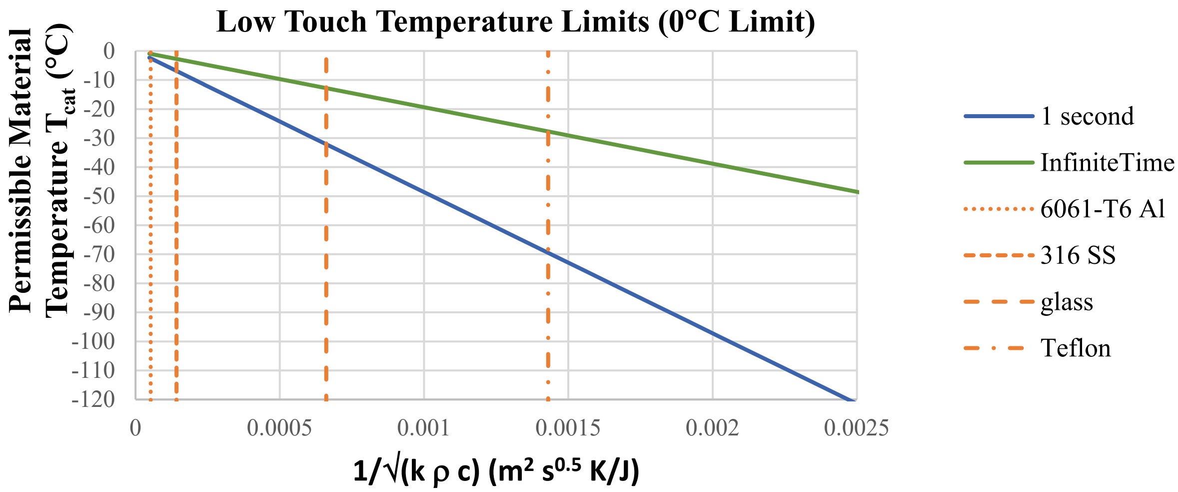


Figure 9.3-5—Low T_{cat} for Incidental and Intentional (Planned) Contact (0°C)

9.3.3 Electrical Shock Hazard Minimization

9.3.3.1 Power Interruption

[V2 9017] The system **shall** provide the crew with capability to control the power to an electrical circuit.

[Rationale: This assumes that, at some point in a mission, crew could come in contact with exposed conductors which could cause electrical shock or arcing and/or molten metal resulting in crew injury/death or equipment damage. Thus, there must be a way for the crew to eliminate this exposure by interrupting power, as opposed to only remote control.]

9.3.3.2 Energized Status

[V2 9018] The system **shall** provide and display the de-energized status (interruption of electrical power) of a circuit to the crew and within their fields of regard.

[Rationale: When de-energizing a system, the user must always be provided with feedback that confirms the function has occurred. For efficiency, the display is to be visible to the crew without having to move from their position. Because of the critical nature of this information, the complexity of some circuits, and the possibility of a false indication, many times circuit status is verified using a separate tool such as an electromagnetic sensor.]

9.3.3.3 Nominal Physiological Electrical Current Limits

[V2 9019] Under nominal situations (routine human contacts to conductive housing), the program **shall** limit electrical current through the crewmember to ≤ (less than or equal to) 0.4 mA for Direct Current (DC) and ≤ (less than or equal to) 0.2 mA peak for Alternating Current (AC).

[Rationale: These values are below the physiological effect of sensation for the most sensitive members of the astronaut population. This requirement is intended to address typical exposure situations where human contact can routinely occur with conductive housing of electrical equipment, and in these situations no perceptible current flow is the design requirement. Typically, NASA engineering teams establish 1 MΩ (Megaohm) isolation along with grounding to conductive surfaces with Class H or better bond to prevent current flow through crewmembers.]

9.3.3.4 Catastrophic Physiological Electrical Current Limits

The following two requirements set the physiological electrical current limits used in hazard analysis (for all circumstances, [V2 9020] Catastrophic Physiological Electrical Current Limits for all Circumstances, and specifically for unique circumstances where startle reaction may cause a catastrophic event, [V2 9021] Catastrophic Physiological Electrical Current Limits for Startle Reaction), for determining hazard severity, failure tolerance, and controls of a system that could pose a catastrophic electrical shock to the human. These thresholds are used when a hazard analysis is considering failure scenarios and off nominal events where failures such as electrical short circuits have compromised system isolation and pose a risk of catastrophic electrical shock to the human.

9.3.3.4.1 Catastrophic Physiological Electrical Current Limits for all Circumstances

[V2 9020] The program **shall** limit the electrical current through the crewmember to ≤ (less than or equal to) 40mA for DC and ≤ (less than or equal to) 8 mA peak for AC to avoid catastrophic physiological effects to the crewmember.

[Rationale: International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The limits for current that could pass through a crewmember were chosen based on the threshold for maintaining muscle control if shocked to protect 99.5% of the population (IEC 60479-2, Effect of current on human beings and livestock, Part 2: Special aspects, Figure 7). This NASA Technical Standard is intended to provide the threshold where additional engineering controls will be required to mitigate the catastrophic nature of electrical shock/physiological effects to the human.

For the above current limits, utilizing the worst-case body impedance of 850 Ω (Ohms) the maximum DC voltage would be 34 volts and the maximum AC voltage would be 6.8 volts. The 850 Ω (Ohms) represents the 5th percentile of the population for a touch voltage of 125 volts *and a large contact area (such as full hand or a surface area of 82 cm^2) in saltwater-wet conditions (IEC 60479-1, Effects of current on human beings and livestock, Part 1: General Aspects, Table 3). Higher body impedances, and thereby higher voltages, may be allowed based on a case-by-case analysis (contact area, wet conditions etc.) utilizing 5% body impedances tables in IEC 60479-1, and with the approval by the appropriate Safety Panel.]*

Note: AC limit is for 50/60 Hz. If different frequencies are required, refer to IEC 60479-2, Figure 2. For different waveshapes and AC/DC combinations, refer to IEC 60479-2 limits. For voltage spikes of short duration (<1 second), refer to IEC TR 60479-5, Effects of current on human beings and livestock, Part 5: Touch voltage threshold values for physiological effects, for limits (Figure 5, curve c1 for AC and Figure 14, curve c1 for DC).

9.3.3.4.2 Catastrophic Physiological Electrical Current Limits for Startle Reaction

[V2 9021] During critical operations where a startle reaction is possible, the program **shall** limit electrical current through the crewmember to ≤ (less than or equal to) 2 mA for DC and ≤ (less than or equal to) 0.5 mA for AC to avoid potentially catastrophic conditions.

[Rationale: IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The current values were chosen based on the threshold for a startle reaction if shocked (IEC TR 60479-5, Effects of current on human beings and livestock, Part 5: Touch voltage threshold values for physiological effects, Table 1). Under certain circumstances such as startle reaction, more restrictive thresholds than the physiological catastrophic limits ([V2 9020] Catastrophic Physiological Electrical Current Limits for all Circumstances) may be employed in hazard and risk assessments. Consider the terrestrial examples of involuntary reaction and let go thresholds.

For a person at rest in a chair not performing a critical task, these exposures are not catastrophic. However, consider an electrician on a ladder or the pilot of an aircraft where split-second involuntary reactions can have dire consequences where the threshold of safety must be set lower at the startle reaction electrical current values. The application of these lower thresholds would be case-by-case in unique circumstances where it is deemed appropriate, such as during manual control of a spacecraft or during EVA. For the above current limits, utilizing the worst-case body impedance of 850 Ω (Ohms), the maximum DC voltage would be 1.7 volts and the maximum AC voltage would be 0.4 volts. The 850 Ω (Ohms) represents the 5th percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm2) in saltwater-wet conditions (IEC 60479-1, Effects of current on human beings and livestock, Part 1: General Aspects, Table 3). Higher body impedances, and, thereby, higher voltages, may be allowed based on a case-by-case analysis (contact area, wet conditions, etc.) utilizing 5% body impedances tables in IEC 60479-1 and with the approval by the appropriate Safety Panel.

Note: AC voltage is for 50/60 Hz. If different frequencies are required, refer to IEC 60479-2, Effect of current on human beings and livestock, Part 2: Special aspects, Figure 2. For different wave shapes and AC/DC combinations, refer to IEC 60479-2 limits.]

9.3.3.5 Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds

[V2 9022] The program/project **shall** use the 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC 60479-1, Effects of current on human beings and livestock - Part 1: General Aspects, to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.

[Rationale: IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. For example, 850 Ω (Ohm) represents the 5th percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm^2) in saltwater-wet conditions (IEC 60479-1, Table 3). Higher body impedances and, thereby, higher voltages, may be allowed based on a case-by-case analysis utilizing 5% body impedances tables with the approval of the program's Safety Panel. Higher body impedances and, thereby, higher voltages, may be allowed based on a case-by-case analysis utilizing 5% body impedances tables with the approval of the program's Safety Panel.]

9.3.3.6 Leakage Currents – Medical and Bioinstrumentation Equipment

[V2 9023] For equipment such as bioinstrumentation and medical devices, that are specifically designed to contact the human body, electrical leakage currents caused by contact with exposed surfaces (including in worst-case fault scenarios) **shall** be kept below the levels specified in Table 9.3-11—Leakage Currents-Medical and Bioinstrumentation Equipment.

[Rationale: Some equipment needs to pass small amounts of current through the body to accomplish its intended function, e.g., bias currents in medical monitoring equipment. The amount of current allowed depends on the frequency and whether the part of the equipment contacting the crewmember is isolated from the power source. Examples of isolated equipment are intra-aortic catheters and electrocardiogram (ECG) monitors. Examples of non-isolated equipment are blood pressure cuffs and digital thermometers. These levels of leakage current are consistent with those in IEC 60601-1, Medical Electrical Equipment – Part 1: General Requirements for Basic Safety and Essential Performance, for patient auxiliary and patient leakage currents in isolated (type CF) and non-isolated (types B and BF) equipment. These leakage currents are measured across parts applied to the crewmember and from the applied parts to ground. The summation of all the currents must be compared to the current limits in Table 9.3-11. Architectural contributions, such as an independent current monitor with interlock, can prevent dangerous currents in the case of equipment fault scenarios.]

Table 9.3-11—Leakage Currents – Medical and Bioinstrumentation Equipment

<table>
<tr><th colspan="5">Maximum Current (mA)</th></tr>
<tr><th rowspan="2">Body Contact</th><th rowspan="2">Frequency</th><th rowspan="2">Operating Condition</th><th colspan="2">Equipment Type</th></tr>
<tr><th>Isolated Equipment</th><th>Non-Isolated Equipment</th></tr>
<tr><td rowspan="4">External*</td><td rowspan="2">DC to 1 kHz</td><td>Normal</td><td colspan="2">0.1</td></tr>
<tr><td>Single Fault</td><td colspan="2">0.5</td></tr>
<tr><td rowspan="2">>1 kHz</td><td>Normal</td><td colspan="2">f (kHz) x 0.1 (must be ≤ 5)</td></tr>
<tr><td>Single Fault</td><td colspan="2">f (kHz) x 0.5 (must be ≤ 5)</td></tr>
<tr><td rowspan="4">Internal</td><td rowspan="2">DC to 1 kHz</td><td>Normal</td><td>0.01</td><td rowspan="4">Not Allowed</td></tr>
<tr><td>Single Fault</td><td>0.05</td></tr>
<tr><td rowspan="2">>1 kHz</td><td>Normal</td><td>f (kHz) x 0.01 (must be ≤ 1)</td></tr>
<tr><td>Single Fault</td><td>f (kHz) x 0.05 (must be ≤ 1)</td></tr>
<tr><td colspan="5">*For DC, there is a small risk of heating and tissue necrosis for prolonged duration of contact.</td></tr>
</table>

9.3.4 Fluid and Gas Spill Hazard Minimization

9.3.4.1 Fluid/Gas Release

[V2 9024] Hardware and equipment **shall not** release stored fluids or gases in a manner that causes injury to the crew.

[Rationale: Crew injuries are likely to be caused by either highly pressurized fluids and gases or toxic fluids and gases. In both cases, design requirements are to be developed so that the crew is protected during both storage and handling of these fluids and gases.]

9.3.4.2 Fluid/Gas Isolation

[V2 9025] The system **shall** provide for the isolation or shutoff of fluids in hardware and equipment.

[Rationale: Fluids are most likely to be temporarily shut off at service and maintenance points. System developers are to identify those points and create isolation capabilities. Without dedicated isolation controls, crews could create bypasses, which waste crew time and possibly damage systems. Also, to save time and reduce the possibilities of error, e.g., forgetting to shut them off or to turn them back on when maintenance is complete, the shut-off valves are to be located near those service points and operable while wearing the most encumbering equipment and clothing anticipated.

Note: The term fluid includes both liquid as well as gas.]

9.3.4.3 Fluid/Gas Containment

[V2 9026] The system **shall** provide for containment and disposal of fluids that might be released during operation or maintenance.

[Rationale: Excess fluids are likely to be released during draining and filling of systems. Designs are to accommodate these possibilities to ensure free fluid control, collection, containment, or disposal that is safe and effective. Some examples of control, collection, and disposal methods include fluid-sealed connectors, volume sensors, flow sensors, overflow valves, accumulators, vacuum systems, and system waste venting. Collection and containment facilities are to be located near the points where release is likely to occur (maintenance or service points). Control of unexpected gas and fluid release due to system or component failure are to be assessed by safety hazard analysis. This requirement applies to fluids under the system's control.]

9.4 Durability

9.4.1 Equipment Protection

[V2 9027] Systems, hardware, and equipment **shall** be protected from and be capable of withstanding forces imposed intentionally or unintentionally by the crew.

[Rationale: Unintentional damage can occur if items are in a location where crew is focused on other activities such as translation, moving equipment, or maintaining other systems. Designers are to identify areas of crew activity and decide if exposed hardware and equipment are sufficiently durable for unintended forces. Such hardware and equipment may have to be relocated, guarded, covered, e.g., with close-out panels, or simply designed to be more durable. "Intentional" damage may result from crewmembers securing or tightening items (latches, retainers, bolts, screws, etc.) using forces beyond their design limits. This often occurs under panic conditions. Hardware designers are to use crew strength data and to assume the crew could apply their maximum strength forces.]

9.4.2 Isolation of Crew from Spacecraft Equipment

[V2 9028] Protective provisions, e.g., close-out panels, **shall** be provided to isolate and separate equipment from the crew within the habitable volume.

[Rationale: Protective provisions such as closeout panels serve the following functions: provide protection from forces in accordance with [V2 9027] Equipment Protection, in this NASA Technical Standard; provide fire abatement protection and isolation and support of fire extinguishing operations; protect crew from ignition sources and sharp edges and retain debris from coming out into habitable volume; protect equipment from ground or flight crew operations; provide acoustic barrier for noise generated behind panels; minimize snag potential; and prevent loose items or equipment from becoming lost. In addition, protective provisions are designed to provide a smooth surface, faired-in with the adjacent crew compartment structure, and be compatible with crew passageway requirements.]

9.5 Assembly and Disassembly

9.5.1 Hardware and Equipment Mounting and Installation

[V2 9029] System hardware and equipment **shall** be designed so that it cannot be mounted or installed improperly.

[Rationale: Ideally, similar items are interchangeable. The preferred method of preventing improper installation and mating is a design that prevents it such as misaligned mounting holes, pins, or keys. The designs to prevent installation and mating errors are to be rugged enough to withstand persistent attempts. Cues (such as color or labeling) can be provided to remind crewmembers, so they save the time of trying to make improper installations. However, these cues are not to be the sole countermeasure to improper installation and mating.]

9.5.2 Mating and Demating

9.5.2.1 Connector Spacing

[V2 9030] The spacing between connectors **shall** permit mating and demating by crewmembers wearing expected clothing.

[Rationale: Adequate access and working space allows personnel to efficiently access equipment in a way that allows nominal and off-nominal tasks to be performed. Access to connectors may be required during equipment assembly, reconfiguration, or maintenance. Access and work envelopes are different for differing tasks. In particular, protective garments, e.g., spacesuits, may be required by the flight crew and are to be accommodated.]

9.5.2.2 Connector Actuation without Tools

[V2 9031] Connectors **shall** be operable without tools for mating and demating while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Connector actuation includes mating/connecting and demating/disconnecting of a connection. Lost or damaged tools prevent connectors from being connected or disconnected, which may result in loss of crew (LOC) or loss of mission (LOM).]

9.5.2.3 Incorrect Mating, Demating Prevention

[V2 9032] Cable, gas and fluid lines, and electrical umbilical connectors **shall** prevent potential mismating and damage associated with mating or demating tasks.

[Rationale: Ideally, similar items are interchangeable. The preferred method of preventing improper installation and mating is a design that prevents it such as misaligned mounting holes, pins, or keys. The designs to prevent installation and mating errors are to be rugged enough to withstand persistent attempts. Cues (such as color or labeling) can be provided to remind

crewmembers, so they save the time of trying to make improper installations. However, these cues are not to be the sole countermeasure to improper installation and mating.]

9.5.2.4 Mating, Demating Hazards

[V2 9033] The system **shall not** subject personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy, during mating or demating.

[Rationale: Maintenance or service tasks are not likely to be familiar, and thus crews may be more focused on these tasks. Hazards that would normally be identified and avoided may go unnoticed during maintenance. Design requirements and solutions are to identify hazards that are exposed during maintenance activities and determine ways to eliminate these hazards or protect the crew from them.]

9.6 Cable Management

9.6.1 Cable Management

[V2 9034] The system **shall** manage cable, wire, and hose location, protection, routing, and retention to prevent physical interference with crew operations and safety.

[Rationale: Designers are to define areas of activity and route fixed lines and cables so that they are both protected and also do not interfere with these activities. Pressurized lines and hoses must be restrained to prevent crew injury. Also, system designers are to focus on non-fixed lines and cables that may be unstowed or moved for a specific task or temporary rearrangement. While the rerouted cable or line may accommodate a specific need, the routing path may interfere with other, non-related activities such as crew translation and egress. Designers are to identify potential uses for lines and cables and ensure the start points, end points, and cable and line routes in between accommodate all crew activities.]

9.7 Design for Maintainability

Maintenance constitutes a large portion of a system lifecycle, and it can consume a significant amount of time during a mission. Designing for maintainability involves system level optimization for parts, analyzing the resulting ergonomics, and considering tools and information as part of the design.

9.7.1 General

9.7.1.1 Maintenance Concept of Operations

[V2 9111] For each maintenance-level item, the human spaceflight program **shall** define and document a maintenance operational concept considering the following factors, as a minimum, and updated throughout the design lifecycle:

a. Mission work natural environment (e.g., dust, lighting, heating, atmosphere, gravity) as specified in program requirements for natural environments (e.g., SLS-SPEC-159 Cross Program Design Specification for Natural Environments (DSNE)).

b. Tools, aids, and support equipment available to the maintainers in-situ.

c. Skill-level of the maintainers (i.e., crewmembers).

d. Access needed to equipment – considering mission-criticality, urgency of repair, anticipated frequency of servicing, and complexity of approach.

e. Reliability- or performance-driven preventive maintenance schedule.

f. Preventive and corrective maintenance plans.

g. Total crew time and number of crew needed.

[Rationale: Maintenance level items are assembled units or modules that are designed to be isolated from the rest of its system, removed, maintained, repaired, and/or replaced by the maintainer on-mission. Certain subsystems are so crucial to survival they need to be identified to drive modularity and sparing of the entire system. Maintenance-level items and subsystems are identified through the trade space analysis considering the following factors, among others: reliability, redundancy, functionality sustainment, stress reduction, derating, accessibility, modularity, and condition-based monitoring. If proper attention and emphasis is not placed on supportability concerns and issues, particularly early in a program, then the potential undesired impacts to operations can be significant. NASA has been able to shift maintainability requirements from design phase to operations because ground support can be increased throughout the mission. This will not be possible to the same extent with longer lunar surface operations where vehicles and equipment will reside on the Moon. The same will be true for Mars compounded by long communication latencies that will not allow ground to provide real-time guidance and oversight for preventive and corrective maintenance tasks. In addition, environmental factors associated with surface operations, including dust, thermal extremes, day to night transitions, static electricity, dormancy, etc., will increase maintainability challenges. Standards and requirements for supportability, must be implemented early in missions beyond low-Earth orbit utilizing technologies that cannot be repaired on Earth and cannot be replaced from Earth. Impacts of not developing a Maintenance ConOps include loss of a mission or loss of life given the communication latencies, resupply challenges and evacuation constraints of NASA's long-duration missions (e.g., Lunar and Martian DRMs).]

9.7.1.2 Availability of Critical Systems

[V2 9112] System repairs and/or replacements **shall** be designed to be completed within the time-to-effect margin.

[Rationale: Mission success is dependent on the availability of the critical systems that keep the crew safe and enable completion of mission objectives. System reliability is one approach to assuring availability. If reliability cannot be guaranteed, corrective maintenance and contingency plans are needed to assure system operation. System availability requirements may be time constrained depending on system availability requirements. Operational factors, including available onboard resources, crew capabilities, and environmental constraints, affect the design and feasibility of corrective maintenance activities. If repairs/replacements cannot be completed in within the time-to-effect margin (NASA, 2021; Kennedy Space Center Office of Mission Assurance, 2015), alternative design strategies (e.g., redundancy) need to be utilized to maintain critical functionality.]

9.7.1.3 Damage Prevention

[V2 9113] The system **shall** be designed to prevent damage during maintenance.

[Rationale: Maintenance activities can lead to increased failures because there is risk to the subject system and proximate systems each time the system is opened or disturbed, especially when systems are not designed for maintainability. Designing the system to the physical capabilities and limitations of the maintainer (e.g., ensuring parts are accessible by hand) prevents collateral and inherent damage when proper procedures are followed. Designing systems to contain failure effects, minimize failure propagation, and minimize interaction with proximate systems also reduces the risk of collateral damage during maintenance. Designs and maintenance strategies are to be analyzed (e.g., failure/process analysis) for feasibility and risk prior to incorporation.]

9.7.1.4 In-Mission Maintenance

[V2 9114] The program **shall** design all flight hardware and software to facilitate in-mission preventive and corrective maintenance and check-out.

[Rationale: Crew and vehicle health and the ability to meet mission objectives require that maintenance and check-out activities be achieved with efficiency and accuracy. Design considerations, e.g., tool interfaces, can significantly impact the performance of these activities. Maintainability and its characteristics are to be considered in the design trade space.]

9.7.1.5 Design for Maintenance

[V2 9036] The system **shall** provide the means necessary for the crew to safely and efficiently perform routine service, maintenance, and anticipated unscheduled maintenance activities while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Reduction in the time devoted to maintenance and servicing can mean more crew time devoted to achieving mission goals. Also, because of the complexity of space missions and the interdependency of many factors (equipment, supplies, weather, solar flares, political considerations, etc.), designs are to minimize reliance on outside maintenance support. Designs

are to provide the tools, parts, supplies, training, and documentation necessary for crews to maintain efficient and safe operations.]

9.7.1.6 Commercial Off-the-Shelf (COTS) Equipment Maintenance

[V2 9037] Maintenance for commercial off-the-shelf equipment **shall** be suitable to the spaceflight environment.

[Rationale: Systems designed for terrestrial environments may be adapted for space missions. This adaptation is to include procedures and features that will allow maintenance tasks to be performed safely and effectively in a space mission environment. Major changes that likely need accommodation are differences in gravity or crewmembers wearing gloves.]

9.7.2 Tools and Test Equipment

9.7.2.1 In-Mission Tool Set

[V2 9038] The program **shall** establish a common set of in-mission tools and test equipment for spaceflight and surface systems.

[Rationale: Establishing a common set of tools with which all mission systems can be maintained minimizes mass and complexity, reduces training demands, and increases redundancy for a given mission. Tool set design is to be based partly on reducing the demands on the crew: selecting tools that are likely to be familiar to crewmembers and minimizing the number of different tools. IVA and EVA tools generally differ due to the unique requirements imposed by the EVA environment, therefore a common set of IVA and a common set of EVA tools with as much overlap as possible is a primary goal of this requirement. The other primary goal of this requirement is to have a common set of tools for all phases of the mission to be used across all elements of the mission (e.g., transportation vehicle, orbital outpost, lander, surface habitat, and surface systems should all use the same common toolkit). Apollo and ISS lessons learned indicate that tool set design is also to consider the complement of tools and equipment needed to respond to unexpected failures and hardware workarounds. Having a comprehensive and common tool set is especially important for future long-duration missions with constrained or nonexistent resupply operations.]

9.7.2.2 Maintenance Tools Usability

[V2 9115] Tools and test equipment **shall** be usable by the full range of crew sizes and strengths wearing any personal protective equipment (PPE).

[Rationale: Crew members of varying size and strength need the capability to conduct maintenance activities under a variety of conditions. Ensuring tools and test equipment are usable under the most encumbering circumstances reduces maintenance time and complexity.]

9.7.2.3 Tool and Test Equipment Commonality

[V2 9116] Systems and units of equipment **shall** be designed so that maintenance can be accomplished with the set of in-mission tools and test equipment.

[Rationale: ISS lessons learned indicate that crews often have difficulty locating the tools and test equipment needed for a given activity, resulting in many hours spent searching for items and delayed maintenance. Tool and test equipment commonality provides redundancy and contributes to crew readiness for unplanned maintenance activities. Interchangeable tools and test equipment improve mass efficiency because common items can cover multiple types of failures. Utilizing common tools and test equipment across vendors increases in importance for missions beyond low-Earth orbit when increasingly complex and limited resupply operations constrain the ability to replace missing or ineffective tools and test equipment while simultaneously limiting the ability to return maintenance items (MIs) to the ground for maintenance. Commonality helps to ensure the right tools and test equipment are available at the right time to crewmembers in-mission.]

9.7.2.4 Tool Clearance

[V2 9050] The system **shall** provide tool clearances for tool installation and actuation for all tool interfaces during in-mission maintenance.

[Rationale: Tools to be used for in-mission maintenance are to be identified by the hardware developer, and clearance for application is to be accommodated to ensure that maintenance tasks can be performed.]

9.7.3 Maintenance Efficiency

9.7.3.1 Maintenance Time

[V2 9039] Planned maintenance for systems and associated hardware and equipment **shall** be capable of being performed within the allotted crew schedule while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Maintenance and servicing are directly related to the amount of time available for mission goals. Reduction in the time devoted to maintenance and servicing means more crew time devoted to achieving mission goals. Also, because of the complexity of space missions and the interdependency of many factors (equipment, supplies, weather, solar flares, changes in mission design and objectives, etc.), designs are to be self-sufficient and minimize reliance on outside maintenance support. Designs are to provide the tools and mechanisms (including cleaning), parts (as modular units where possible), supplies, training, and documentation necessary for crews to maintain efficient and safe operations. Crew schedule allotted for planned maintenance is to include time associated with dust management and cleaning.]

9.7.3.2 Captive Fasteners

[V2 9042] Fasteners used by the crew during maintenance **shall** be captive.

[Rationale: Freed fasteners become Foreign Object Debris (FOD) in microgravity, which pose a risk during the mission. Fasteners can be lost either by loosening during normal use or by becoming misplaced during maintenance operations. Space missions are generally isolated, and replacement parts are not available. This is particularly important in zero gravity environments because small items such as fasteners can be very difficult to find.]

9.7.3.3 Minimum Number of Fasteners – Item

[V2 9043] For items that may be serviceable by the crew, the number of fasteners used **shall** be the minimum required to meet structural engineering integrity requirements.

[Rationale: Designers can add a safety factor to some configurations by increasing the number of fasteners. However, when crews are to routinely remove the fasteners, selection of the number of fasteners is also to consider reduction of crew time devoted to maintenance activities.]

9.7.3.4 Minimum Variety of Fasteners – System

[V2 9044] The system **shall** be serviceable with a common set of fasteners that meet structural integrity requirements.

[Rationale: Different fasteners require different tools and procedures for removal and replacement. Commonality of fasteners can reduce times to access and the need for different tools. It can also reduce training times necessary to introduce crews to the fastener types.]

9.7.4 Accessibility

9.7.4.1 Access Using Available Tools

[V2 9117] Systems and units of equipment that require maintenance **shall** be accessible and openable during the mission using the on-board tool set.

[Rationale: Accessibility is a key characteristic of system maintainability, and therefore to system availability. Even if the equipment does not require preventive maintenance, or is not anticipated, due to reliability estimates, to require corrective maintenance, it may need to be accessed and opened due to unforeseen events. Further, logistical constraints of missions beyond LEO will require maintenance to be performed at an intermediate level—e.g., that below the maintenance item (MI) level. ISS experience has shown that intermediate level maintenance is problematic if not all parts of the MI are designed to be accessed or repaired (Bertels, 2006). As sparing will be limited during extended missions without access to frequent resupply, it may also be necessary to scavenge parts from operating equipment to replace failed parts in higher

priority systems. System designers consider the physical capabilities of crewmembers and the factors of the environment (e.g., limited gravity, physical space) when assessing accessibility.]

9.7.4.2 Maintenance Item Location

[V2 9045] The system **shall** ensure maintenance access to the items prioritized [V2 9111] Maintenance Concept of Operations, so that the maintenance task does not require the removal or disabling of other systems or components (excluding access panels).

[Rationale: Location of items depends on many factors (physical room, interface with other items, manufacturing considerations, etc.), and maintenance can be easily overlooked. It is important, therefore, that, early in a design, system developers identify those items that will require frequent and/or critical maintenance. Accessibility to critical items and those items requiring frequent servicing is a priority. Deintegrating and demating is a source of risk during maintenance. Required electrical and pressure and fluid system safing are exempt from this requirement.

Requirement to be verified using maintenance task analysis.]

9.7.4.3 Check and Service Point Accessibility

[V2 9046] Check points and service points for systems, hardware, and equipment **shall** be directly accessible while wearing the most encumbering equipment and clothing anticipated.

[Rationale: System designs are to support mission goals that do not normally devote crew time to maintenance tasks. Removal of items to access check and service points increases maintenance times. Also, complex and time-intensive maintenance procedures could discourage performance of scheduled tasks.]

9.7.4.4 Maintenance Accommodation

[V2 9047] Physical work access envelopes **shall** accommodate the crew, required tools, and any protective equipment needed to perform maintenance.

[Rationale: Maintenance tasks are to be defined and analyzed with worst-case assumptions. Volume is to be provided to allow the size extremes in the crewmembers performing the tasks using proper tools and protective equipment within the prescribed times. Hand clearance for in-flight maintenance tasks is to be provided by the hardware developer to ensure that maintenance tasks can be performed while wearing the most encumbering equipment and clothing anticipated.]

9.7.4.5 Visual Access for Maintenance

[V2 9048] Maintenance tasks that require visual feedback **shall** be directly visible during task performance while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Efficient and safe performance of many maintenance tasks requires vision during task performance. In crowded spaces, hands and tools can block vision of the task. On those tasks that require vision during task performance (such as alignments or adjustments), designers are to locate and design equipment to provide this vision.]

9.7.5 Visibility and Identifiability

9.7.5.1 Component Identification

[V2 9118] Flight systems **shall** include information and labeling that enables the crew to correctly locate, handle, and identify the systems components.

[Rationale: When beginning a maintenance activity, crewmembers often spend time up-front locating, identifying, and familiarizing themselves with the components. Clear and informative labeling can streamline this process, and help crew properly contextualize the component within the larger system. Unique identifications that enable rapid recognition among similar items reduce maintenance time. Consistency in the manner of identification across items decreases the time needed for locating and interpreting identifications. Identifications that enable rapid recognition without the use of conversion tables are less susceptible to errors. Redundant identifications give maintainers more than one opportunity to identify the item, increasing maintenance efficiency. It is important to provide an accurate representation of the interior of any flight hardware unit that can be opened, both to ensure crew safety and to prevent damage to the system. Refer to [V2 10151] Labeling Plan and Icon Library for guidance on labeling, as well as label specifications found in Appendix F.5.2. A program-wide labeling plan and icon library are to specify and document characteristics of the labels and icons used in human interface. Additional design standards for cables, wires, and harnesses can be found in NASA-STD-8739.4 Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring.]

9.7.5.2 Cable Identification

[V2 9035] All maintainable cables, wires, and hoses **shall** be uniquely and consistently identified at the maintenance point.

[Rationale: Locating and identifying the specific cable, wire, or hose needed for a maintenance activity can be time consuming. Unique identifications that enable rapid recognition among similar items reduce maintenance time. Consistency in the manner of identification across items decreases the time needed for locating and interpreting identifications. Identifications that enable rapid recognition without the use of conversion tables are less susceptible to errors. Redundant identifications give maintainers more than one opportunity to identify the item, increasing maintenance efficiency. Some conductors do not terminate in a keyed connector; they are individually attached. It is essential that the conductors be attached to the correct terminal points. All individual conductors that attach to different terminal points are to be coded. Terminal points are normally fixed and can be identified with labels and illustrations.

Conductors, on the other hand, are to have identifications affixed to them. This is normally done with color coding of the insulation materials or by tagging the conductors. Refer to [V2 10151] Labeling Plan and Icon Library for guidance on labeling. A program-wide labeling plan and icon library are to specify and document characteristics of the labels and icons used in human interface. Additional design standards for cables, wires, and harnesses can be found in NASA STD 8739.4.]

9.7.5.3 Visual Aids for Maintenance

[V2 9119] For maintenance activities, visual aids **shall** be provided with appropriate scale, orientation, and context to enable crew to locate and identify components and execute the task.

[Rationale: Locating and identifying all the components involved in a maintenance procedure can be time-consuming, especially when a crewmember is working with an unfamiliar system. Photos, videos, and other graphics are invaluable for providing context, and their use can accelerate pre-maintenance preparation and procedure execution. Visual aids are to be accurate to the operational environment and provide the appropriate amount of detail for the task to enable efficiency. Sparse or misleading visual cues can contribute to spatial disorientation (Bloomberg 2016) and influence astronauts' ability to accurately perform cognitive and sensorimotor tasks (Clément et al. 2013). Appropriate visual aids are increasingly important for exploration beyond LEO, where lower-level onboard maintenance will be necessary, and oversight from the ground will be limited. Visual aids may be provided digitally and/or within a procedure. Interactive visual aids that enable crew to dynamically resize and rotate should be considered to amplify crewmembers' understanding of the system context. Using the same visual aids in pre-mission training may be helpful to build crew familiarity with both the system and the visual aids.]

9.7.6 Failure Detection and Notification

9.7.6.1 Fault Detection

[V2 9051] Unit of equipment undergoing maintenance **shall** provide rapid and positive fault detection and isolation of defective items.

[Rationale: Fault detection is a means to reduce crew time devoted to maintenance activities. Properly designed aids to fault detection and isolation can also reduce crew training requirements. Terminology, references, and graphics used are to be coordinated with other crew task demands to minimize additional training. Designers are to define systems that are likely to fail and then create features that help identify these failures when they occur. In addition to the fault detection and isolation capabilities, the crew is to be provided tools and supplies to maintain and repair the defective systems.]

9.7.6.2 Failure Notification

[V2 9052] The system **shall** alert the crew when critical equipment has failed or is not operating within tolerance limits.

[Rationale: An alerting system allows crew to quickly surmise a system or component failure. Terminology, references, and graphics used are to be coordinated with other crew task demands to minimize additional training.]

9.7.7 Maintenance Data

9.7.7.1 Condition Monitoring

[V2 9120] The system **shall** be designed to provide condition-monitoring data to an information system that can be accessed by the crew, to maintenance data systems or mission control. (See also [V2 10124 Data Availability.)

[Rationale: Monitoring is needed to optimize maintenance action plans and improve system availability. Reliability estimates are often conservative, leading to unnecessary preventive maintenance (NASA RCM Guide, 2000). Many preventive maintenance tasks achieve nothing, while some are actively counterproductive and even dangerous (Mowbray, 1997); maintenance tasks are prone to human error, (Hobbs, 2021) and the risk of damage is increased each time a system is opened. Condition monitoring provides maintenance triggers, reducing the need for interval-based maintenance. Condition monitoring reduces the reliance on reliability data to ensure availability, ultimately improving crew safety and efficiency. New cost-effective, low-mass technologies increase the value of condition monitoring for missions beyond LEO.]

9.7.7.2 Maintenance Management Information

[V2 9121] For each maintenance-level item, as a minimum, the following data **shall** be captured and made/available to the crew:

a. Procedures

b. Visual aids

c. Functional state data (e.g., power, temperature, pressure, standby)

d. Active indication of critical procedure step completion

e. Active indication of restored functionality

f. Replacement unit maintenance history

g. Procedure execution records

[Rationale: Maintenance management information enables maintainers to make informed decisions about when and how to perform maintenance with decreasing real-time ground support. Real-time maintenance triggers reduce the reliance on reliability data and eliminate unnecessary preventive maintenance tasks.]

9.7.7.3 Fault Management Information

[V2 9122] For maintenance-level items experiencing off-nominal performance, the following data **shall** be made available to the crew in real-time:

a. Live diagnostic sensor data

b. Troubleshooting steps and decision trees

c. Description of possible faults and locations

d. Description of test points and normal reading ranges

e. Test result interpretations and corrective action recommendations

[Rationale: Fault management information enables maintainers to make informed decisions about when and how to perform corrective maintenance with decreasing real-time ground support. Real-time maintenance triggers reduce the reliance on reliability data and help address unexpected, corrective maintenance efficiently.]

9.7.8 Diagnosis and Troubleshooting

9.7.8.1 Maintenance Activities

[V2 9123] Maintenance activities **shall** be designed to the skillset common to all crewmembers at the time of maintenance.

[Rationale: Effectively leveraging crew capabilities is especially important for exploration beyond LEO, where intermittent and delayed communication with the ground necessitates greater crew autonomy in executing preventive and corrective maintenance tasks. Designing equipment based on the basic abilities and limitations of crew to accomplish the assigned tasks will enable increasingly Earth-independent procedure execution, with reduced guidance and oversight from the ground. The skill-level of crewmembers can also be increased using "just-in-time" onboard training that is specific to the situation or system. This method may be useful in situations in which mass constraints prevent the reduction of system complexity. Designing maintenance tasks based on the capabilities of the maintainer (as opposed to the provider) can reduce errors, reduce training time, reduce workload, and decrease task execution time.]

9.7.8.2 Maintenance Decision Aids

[V2 9124] For corrective maintenance activities, decision aids **shall** be provided to support diagnosis, troubleshooting, and procedure execution at the expertise-level common to all crewmembers.

[Rationale: For exploration beyond LEO, intermittent and delayed communication with the ground necessitates greater crew autonomy in managing unanticipated vehicle maintenance. In lieu of continuous ground support decision aids are needed to assist crewmembers in identifying possible causes of anomalies and making time-critical decisions with situational uncertainty. A sequence of trouble-shooting checks is to be specified at the skill-level (e.g., training, experience) of the maintainer. To maximize the effectiveness of decision aids, the system needs to be designed to minimize ambiguity groups (possible failure points) and support its recommendation with relevant data.]

9.7.8.3 Verification of Repair

[V2 9125] Preventive and corrective maintenance **shall** include means for verification of successful completion.

[Rationale: Verification can be provided through system self-test, external measurements, or other methods. Repair activities inherently introduce risk to a system; the repair itself may be unsuccessful or maintainers may cause further damage during the repair process. On missions beyond low-Earth orbit, an indication provided onboard the vehicle at the maintenance location will allow crewmembers to verify repair success without relying on ground teams. Even small communication delays (e.g., 6 to 10 seconds on the surface of the moon) reduce the ground team's ability to oversee repair activities. Crewmembers will conduct more repairs on missions beyond LEO, as the ability to send systems to the ground for detailed investigation and repair is constrained; access to repair data onboard the vehicle will facilitate successful maintenance.]

9.7.9 Environmental Control

9.7.9.1 Contamination Prevention

[V2 9126] For planetary surface missions, maintenance tasks **shall** be designed to prevent environmental contamination (e.g., dust) of maintenance items and EVA systems.

[Rationale: Planetary surface environments have the potential to disrupt operations on the Moon, Mars, and asteroids. Lessons learned from Apollo lunar surface missions indicate that care must be exercised to minimize dust contaminants during maintenance. Maintenance tasks are to be analyzed before application by maintainers to ensure appropriate contamination provisions are in place within procedures. Note: For celestial body in-situ conditions preservation see NASA-STD-8719.27, Implementing Planetary Protection Requirements for Space Flight.]

9.7.9.2 Extreme Environment (EE)

[V2 9127] Equipment, including tools and instruments, that are maintained on the planetary surface **shall** be designed to meet all performance requirements specified in NASA-STD-5017A Design and Development Requirements for Mechanisms during and after exposure to the expected natural environmental conditions specified in the SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE).

[Rationale: Space environment can present EE conditions in pressure, temperature, radiation, and corrosion, including acidic and dust exposure. Certain planned mission operations can also induce EE conditions in heat flux and deceleration (g-loading) during entry, descent, and landing (EDL) phases (Balint et al., 2008). Contamination with lunar dust can affect the function of equipment and instrumentation by degrading seals and valves, breaking down lubricants, jamming moving parts, and creating flow blockages (Cain, 2010). Exposure of space hardware to EE conditions, if not designed and built to sustain, can lead to malfunctions and consequently higher spare requirements and frequent maintenance and servicing needs. Increase in both equipment failures and maintenance and servicing needs means less crew time devoted to achieving mission goals. Designs are to prevent EE conditions from negatively impacting mission objectives and operations.]

9.7.9.3 Dust Tolerance

[V2 9128] Tool and equipment functionality **shall not** reduce below minimum performance specifications due to dust exposure when designs cannot prevent its intrusion.

[Rationale: Planetary surface dust environments have the potential to disrupt operations on the Moon, Mars, and asteroids. Composition and transport mechanisms may vary, but in general, dust can affect crew health, and cause thermal management, erosion, binding, and other issues with equipment, as well as affect crew health. Both active (e.g., cleaning or protecting through external forces) and passive (e.g., pretreating to reduce attraction) technologies may be used to mitigate dust effects. If such technologies are unable to eliminate dust intrusion, then its consequences must be anticipated and controlled. Equipment and tools that cannot be completely protected from dust are to be robust to the dust environment and tolerant of dust effects such that functionality is not adversely compromised. Refer to [V2 7113] Dust Removal for additional guidance. An efficient plan is to be designed and implemented for removing dust from any item exposed to planetary surface dust before entering the airlock. Requirements that include methodologies and best practices for testing systems and hardware that is exposed to dust can be found in NASA-STD-1008 Classifications and Requirements for Testing Systems and Hardware to be Exposed to Dust in Planetary Guidance.]

9.7.9.4 Dust Removal

[V2 9129] Any item exposed to extraterrestrial surface dust brought into the pressurized environments **shall** withstand the planned cleaning methods without damage.

[Rationale: The cohesive properties of lunar dust in a vacuum, augmented by electrostatic properties, tend to make it adhere to anything it contacts. Upon being exposed to a pressurized environment, some of the lunar dust floats up in the atmosphere and becomes widely dispersed. During Apollo missions, dust brought into pressurized environments (lunar modules, command modules) was found to cause irritation to the eyes and lungs of the astronauts, potentially compromising crew health (Gaier, 2005). An efficient plan is to be designed and implemented for removing dust from any item exposed to planetary surface dust before entering the airlock. Program requirements on cleaning methods and cleanliness level are to be established pursuant to Surface Cleanliness Level – Generally Clean as specified in JPR 5322.1 Contamination Control Requirements Manual Table 3-1, or equivalent.]

9.8 Protective and Emergency Equipment

9.8.1 Protective Equipment

9.8.1.1 General

9.8.1.1.1 Protective Equipment

[V2 9053] Protective equipment **shall** be provided to protect the crew from expected hazards.

[Rationale: Protective equipment is not used as a control to protect crew from expected hazards in that design hazard controls, failure tolerance, design for minimum risk is necessary to protect the crew from "expected" hazards. Analyses are to define anticipated hazards and appropriate protective equipment. Protective equipment might include gloves, respirators, goggles, and pressure suits (as specified in [V2 11100] Pressure Suits for Protection from Cabin Depressurization). The equipment is to fit the full range of crewmembers. This might require adjustable gear or multiple sizes (with consideration of the number of crewmembers that may have to use the equipment at the same time). Because the gear could be used under emergency conditions, it is to be located so that it is easily accessed and is to be simple to adjust and don.]

9.8.1.1.2 Protective Equipment Use

[V2 9054] Protective equipment **shall not** interfere with the crew's ability to conduct the nominal or contingency operations that the crew is expected to perform while employing the protective equipment, including communication among crewmembers and with ground personnel.

[Rationale: Analyses are to be performed of the situations and operations in which protective equipment is to be used. This analysis is to define the task demands and the requirements for protective equipment design. Task performance demands might include visibility, range of motion, dexterity, and ability to communicate.]

9.8.1.1.3 Equipment Automation of Rescue Aids

[V2 9055] Automation of protective equipment rescue aids **shall** be provided when the crew cannot perform assigned life-saving tasks.

[Rationale: The crew may need to perform tasks to activate protective equipment operation or to activate rescue aids. If these tasks are to be performed under emergency or stressful conditions (where the crewmember is distracted or disabled), then the tasks are to be automated. An example of an automatically activated protective system is the automatic parachute release device. The emergency locator transmitter in an airplane is an example of an automatically activated rescue system.]

9.8.1.2 Hearing Protection

9.8.1.2.1 Use of Hearing Protection

[V2 9056] The system **shall** meet SPL limits of section 6.6, Acoustics, in this NASA Technical Standard, except where otherwise specified in this NASA Technical Standard, without requiring the use of personal hearing protection.

[Rationale: Hearing protection normally operates by decreasing the level of sound at the ear (passive protection). Normal, long-term operations are to be conducted without the impairment to hearing from hearing protection. This would interfere with the ability to communicate and hear audio signals. In some situations (such as launch and reentry), however, noise levels may be uncontrollably high for relatively short periods. Facilities for communications and audio signals can be adapted so that they are possible in those situations. Requirements are to specify those periods allowing the use of hearing protection, and then designs are to accommodate effective crew functioning during that time.]

9.8.1.2.2 Hearing Protection Provision

[V2 9057] Appropriate personal hearing protection **shall** be provided to the crew during all mission phases for contingency or personal preference.

[Rationale: Crewmembers are to have readily accessible hearing protection for unanticipated high noise levels. Hearing protection is also to be available to block noise according to individual preferences such as for concentration or for sleep.]

9.8.1.2.3 Hearing Protection Interference

[V2 9058] The system **shall** be designed so that hearing protection does not inhibit voice communication, monitoring of systems, and detection of alerts.

[Rationale: Some conditions might temporarily expose the crew to high noise levels. During these periods it is important for crewmembers to maintain ability to communicate via voice systems, monitor systems, and detected vehicle system alerts.]

9.8.2 Fire Protection System

9.8.2.1 Fire Detecting, Warning, and Extinguishing

[V2 9059] The vehicle **shall** have a fire protection system composed of detecting, warning, and extinguishing devices that do not create a hazardous environment to all spacecraft volumes during all mission phases.

[Rationale: Fire protection is to be based on the anticipated nature of the fire and the likely location of the crew in the event of a fire. Automated systems are to be used where crews are not capable of extinguishing fires (large fires or fires where crew could be absent, or fires in volumes inaccessible to the crew). Other systems may be effectively protected with portable extinguishers. Hand-operated extinguishers are to be clearly labeled and easily accessed by the crew. All extinguishing systems are not to create any additional hazardous conditions for the crew.]

9.8.2.2 Fire Protection System Health and Status

[V2 9060] The fire protection system health and status data **shall** be provided to the crew and other mission systems.

[Rationale: Design requirements are to ensure that the crew has the capability of determining the health and status of the fire protection system. The crew is to be aware as soon as possible when the fire protection system has failed or is unreliable.]

9.8.2.3 Fire Protection System Failure Alerting

[V2 9061] The vehicle **shall** be alert the crew of failures to the fire protection system.

[Rationale: Design requirements are to ensure that the crew is notified in the event the fire protection system fails. The crew is to be aware as soon as possible when the fire protection system cannot be relied upon.]

9.8.2.4 Fire Protection System Activation

[V2 9062] The fire protection system **shall** be capable of being manually activated and deactivated.

[Rationale: Automated systems may fail and not respond correctly to a fire or may continue extinguishing after a fire is under control. Design requirements are to ensure that the crew is provided with a fire protection system that allows for manual activation and deactivation.]

9.8.2.5 Portable Fire Extinguishers

[V2 9063] A fire protection system **shall** include manually operated portable fire extinguishers usable while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Small fires might be detected and controlled early (before detection by an automated system). Design requirements are to ensure that the crew is provided with a portable fire-fighting capability, even if a fixed firefighting system is provided.]

9.8.3 Emergency Equipment Accessibility

[V2 9064] Emergency equipment **shall** be clearly identified, accessible, and useable to complete emergency response in the time required during all mission phases where the corresponding emergency may occur while wearing the most encumbering equipment and clothing anticipated.

[Rationale: Design requirements are to consider all emergency scenarios requiring access to emergency equipment. Clear identification of emergency equipment includes markings, placards, labels, or etchings. The location and proximity of emergency equipment, with respect to the crew, impacts the accessibility of emergency equipment. For equipment to be usable, its design must consider the crew-system interfaces to allow crew to safely, accurately, and completely respond to the emergency (e.g., fire). The design must also account for the effects of the specific environment where the equipment may be used (e.g., microgravity, partial gravity). Requirements need to be defined in terms of time constraints to perform emergency actions. Furthermore, each emergency may have a unique time requirement and, therefore, a different constraint on access. Refer to the Human Integration Design Handbook (HIDH) for guidance on emergency response times, including fire extinguishment times.]

10. CREW INTERFACES

This section covers the crew interfaces through which static and dynamic information is exchanged between the crew and the system (primarily through controls and displays). Well-designed crew interfaces are critical for crew safety, optimal human performance, and minimize training.

Displays may be visual, audible, or haptic. Visual displays deliver information by using visible media to present text, graphics, colors, indicator lights, images, video, animations, and symbols. This information can be provided on dynamic displays such as Graphic User Interface (GUIs) or control panels or with static displays, such as labels and placards. Audio displays deliver information using sound and include voice communication and audible alerts . Haptic displays deliver information using the sense of touch by applying forces, vibrations, or motions for the purpose of information presentation.

10.1 Standardization & Consistency

Crew interfaces that are consistent require less crew training, and generally result in fewer operational errors and lower cognitive workload. The most efficient way to promote consistency is through the use of standards.

10.1.1 Crew Interface Consistency

[V2 10005] The system **shall** provide crew interfaces that are consistent in appearance, arrangement, location, and operation throughout systems.

[Rationale: Consistency refers to the level of similarity in visual style and operation with and among different crew interface designs that provide similar functions. This includes displays, controls, and procedures. Systems that have been designed with consistency in mind require less training and feel familiar. The number of different codes and ways of operating are minimized, which reduces crew training, cognitive workload, and operational errors. The use of lower-level design requirements and guidelines that specify the "look" (visual characteristics) and "feel" (style of interaction or operation) can help promote consistency.]

10.1.2 Operations Nomenclature Standardization

[V2 10006] Operational nomenclature **shall** be standardized throughout a system.

[Rationale: It is imperative that spaceflight operations personnel, including all ground personnel and crewmembers, communicate using common nomenclature that unambiguously and uniquely defines all aspects of crew operations. This includes, but is not limited to, defining the operations, the methods employed by the crew, the equipment, hardware and software items used, and any associated data. This nomenclature is also to be common among all operational products, including inventory, commands, procedures, displays, planning products, reference

information, system handbooks, system briefs, mission rules, schematics, and payloads operations products.]

10.1.3 Display Standards

[V2 10150] The system **shall** meet the Display Standard in Appendix F.

[Rationale: A program-wide display standards document and icon library are to specify and archive characteristics of the display design, including text, graphics, and icons. These products result in cost savings due to less crew training and rework and increased safety due to reduced errors with a familiar design and simplified label verification. The display standard is applicable to GUIs and physical hardware displays and indicator lights, such as those found on non-GUI alert, equipment, and control panels. It is not applicable to static displays of information such as labels and placards.]

10.1.4 Labeling Plan and Icon Library

[V2 10151] The system **shall** provide labels that are consistent with a Labeling Plan and Icon Library as established by the program.

[Rationale: A program-wide labeling plan and icon library are to specify and document characteristics of the labels and icons used in human interfaces. These characteristics include location, orientation, material, font, size, style, color, etc., and includes visual examples and vehicle placement. Program-wide documents result in cost savings due to reduced redundancy in development and less crew training. The use of consistent labels and icons promotes increased safety and efficiency due to reduced errors with a consistent design.]

10.2 Information Design & Data Management

10.2.1 Stale, Missing, or Unavailable Data

[V2 10020] The system **shall** provide visual indication when a data parameter is stale, missing, unavailable, or unknown.

[Rationale: The human operator must be made aware/cued when display systems are no longer receiving live telemetry, and data values may be "stale" or missing. The indicator can be the same for stale, missing, or unavailable data or unique indications for each type of data (stale, missing, unavailable, or unknown). Use of standard color and/or symbology to represent missing data prevents misinterpretation and errors regarding the system's state.]

10.2.2 Maximum System Response Times

[V2 10022] The system **shall** provide positive indication of crew-initiated control within the times specified in Table 10.2-1—Maximum System Response Time(s).

[Rationale: A positive indication of control activation is used to acknowledge the system response to the control action. For example, a physical detent, an audible click, an integral light, or a switch position may be used to provide a positive indication of control activation. Timely feedback to inputs is critical for crew to feel they are interacting with a responsive system. Slow response times can result in redundant inputs to the system, which can add to crew confusion and errors. A response time of 0.1 s gives the feeling of instantaneous response, and a response time of 1.0 s keeps the user's flow of thought seamless (Miller, 1968; Card, et al., 1991; Nielsen, 1993, 2010). This technical requirement does not apply to manual piloting tasks.]

Table 10.2-1—Maximum System Response Time(s)

System Response	Example	Maximum Time(s)*
Continuous input: cursor and onscreen dynamic elements	Cursor and symbol motion	0.07 (15 Hz)**
Discrete input: Indication of a visual, auditory, or tactile discrete input	On-screen keystroke echo; click or beep; detent/physical feedback; integral light illuminating	0.1
Update to local element	Display of popup menu	0.5
Display of a requested Graphical User Interface (GUI)	Calling up a new display or display component	1.0
Display of updated data on crew command of a state change	Status of "on" when commanded on; status of "open" when commanded open	1.0
Feedback for commands that cannot be completed within 1 second: Indication that a command or process is in progress	A progress bar showing time remaining or a progress message (i.e., Graphical progress bar, animated swirl, message followed by animated dots)	1.0
Status of the command/process after request completed	After request is completed – status message of success/fail/unknown (i.e., "Command Rejected", "Success", telemetry change "ON" to "OFF")	1.0

** System response time variability with respect to mean response time shall be <= 5%. Note that systems with "Short time to effect" scenarios may require faster response times, as determined in the task analysis.*
*** Polling rate, DPI, and screen refresh rate are factors that affect cursor and screen dynamic elements*

10.2.3 System Latency for Piloting

[V2 10152] The system **shall** provide a display system latency for information elements used in vehicle manual flight control tasks and the monitoring of time critical automated flight control tasks, including translation and rotation, that does not exceed a delay of 50ms.

[Rationale: Information elements used in vehicle piloting tasks, including translation and rotation, are to allow for satisfactory levels of performance as measured by handling qualities ([V2 10004] Handling Qualities – Level 1 and [V2 5052] Handling Qualities – Level 2]) and workload assessments ([V2 5007] Cognitive Workload and [V2 10200] Physical Workload). Display system latency is the time delay between the change in vehicle dynamics and the representation of associated new information on the display (total time from sensors to data presentation on the display). This is required to ensure piloting display elements that translate or rotate will do so smoothly without distracting or objectionable jitter, jerkiness, or ratcheting

effects. Any lag introduced by the display system needs to be consistent with the vehicle control task demands associated with that parameter (e.g., based upon the gain level of the task, and the importance of the parameter of interest in the task).]

10.2.4 Command Confirmation

[V2 10080] The system **shall** require operator confirmation before completing critical, hazardous, irreversible, or destructive commands.

[Rationale: Critical, hazardous, irreversible, or destructive commands are to be prevented from being accidentally issued, which can be accomplished by requesting confirmation from the crew, thus reducing the chance of errors.]

10.2.5 Mode Change Command

[V2 10153] The system **shall** require an explicit command to change between simulation, test, or operational mode.

[Rationale: An explicit action to move between modes raises situation awareness and decreases accidental activation of an unintended mode.]

10.2.6 Critical Information Design

[V2 10113] The system **shall** provide data critical to mission planning, mission operations, system maintenance, and system health and status at an appropriate level of detail in a form that does not require mental transposition or computation, memory, or repetitive navigation.

[Rationale: The system is to provide all types of data needed by the crew to perform their tasks at the proper level of detail needed for each task in such a way that it is rapidly recognized and understood. Information displays include electronic and non-electronic media (e.g., fixed or mobile electronic displays, labels, procedures, placards). Data may be presented on different displays, including mobile devices that are an extension of other display devices or an independent device. Task analysis can help define data and level of detail needed for crew task performance.]

10.2.7 Data Update Rates

[V2 10123] The system **shall** operate at a rate that enables the crew to perform tasks effectively and efficiently, e.g., within acceptable error limits and scheduled operating times.

[Rationale: Response times that are too long prevent the crew from performing tasks effectively and efficiently; thus, minimal system response times are to be established for information management functions.]

10.2.8 Data Availability

[V2 10124] The system **shall** provide the crew with data to perform tasks at each workstation where those tasks are to be performed.

[Rationale: Design requirements are to specify which tasks are to be performed at which workstations and subsequently ensure that all task-relevant data be available at those workstations. This includes the capability for the operator to transport information from a fixed display to another location where there is no permanent display device. This can be accomplished via portable display or printed material. Task and data needs are identified by task analysis.]

10.2.9 Information Management Methods and Tools

[V2 10120] The information management system **shall** provide methods and tools that allow the crew to effectively input, store, receive, display, process, distribute, update, and dispose of mission data.

[Rationale: The system is to provide the hardware and software architecture, including crew interfaces necessary, to manage all of the data in the information management system. Usability testing can help ensure that the information management methods and tools provided are easy to use and effective.]

10.2.10 Information Management Security

[V2 10125] The system **shall** have features for the protection of sensitive and private data, transmission, secure viewing, and sender verification.

[Rationale: Data sensitivity and protection or handling measures are to be identified such that mechanisms for the protection of the data such as encryption or password protection can be put in place.]

10.2.11 Information Management Ground Access

[V2 10126] The system **shall** allow for ground access to perform all onboard database functions without crew intervention.

[Rationale: Ground personnel are to have the capability to access and perform data management functions for all onboard data. Architecture is to be in place to support this as a ground-to-vehicle interaction, without crew participation. This access is to take the following into consideration: data protection, data transmission bandwidth, and—most importantly—visibility to the crew. Although the crew is not required to accomplish these ground-initiated functions, the crew is to be aware that the operations will occur, are presently occurring, or have taken place. Consideration for ground access during real-time crew operations may need to be limited as communication time increases.]

10.2.12 Information Backup and Restoration

[V2 10129] The system **shall** provide for 1) automatic backup and crew restoration of information essential for system functionality, and 2) crew-initiated backup and restoration of information that can be generated or changed by crew during the mission.

[Rationale: Measures such as data backups and data restores are to be in place to ensure that data are protected from accidental loss. Backups are to occur automatically for critical data that cannot be recreated; backups for less critical data are to be initiated on crew request, using standard user interface commands.]

10.2.13 Alternative Information Sources

[V2 10130] The system **shall** provide alternative information sources for use in the event of the loss of the information management system.

[Rationale: In the event that the information management system becomes unavailable, the system needs to ensure that backup information sources are available for critical tasks, e.g., emergency procedures may have paper cue cards.]

10.2.14 Software System Recovery

[V2 10131] The system **shall** be rapidly recoverable from a software system crash.

[Rationale: In the event of a system failure, the information management software is to be sophisticated enough to be rapidly recovered. The minimum time delay that is acceptable before the information management system becomes operational after a system crash is to be identified by the program.]

10.3 Alerts

10.3.1 Distinguishable and Consistent Alerts

[V2 10114] The system **shall** provide distinct visual and audio annunciations to the human operators for emergency, warning, and caution events which require human operator action, and advisory alerts that are necessary for human operator situation awareness as specified in Table 10.3-1—Table Alert Type and Annunciation Table.

[Rationale: Visual and audio annunciations are to be defined and provided for all levels of alerts. Annunciations for emergency, warning and caution alerts are to have dual coding, e.g., be seen and heard, and are to be distinctive and identifiable. Advisory alerts may or may not have audio tones associated with this class of alert. Audio annunciations can incorporate speech alarms as a way to provide information efficiently and effectively promote quick and accurate responses from human operators.]

10.3.2 Alert Prioritization

[V2 10175] The System **shall** prioritize alerts per Table 10.3-1—Table Alert Type and Annunciation Table.

[Rationale: Prioritization of auditory and visual alerts is required to avoid different simultaneous alerts, so that crew's attention is focused on the most critical alert. If multiple alerts trigger simultaneously, the system continuously annunciates the highest priority alert until it is acknowledged by the crew. Strategies will need to be developed to manage multiple alerts within a priority. Examples of such strategies include 1) a speech alert that states multiple alerts are in effect, or 2) establishment of sub-priorities within a priority level (e.g., some warnings may be more severe than other warnings, and prioritized for annunciation).]

10.3.3 Reduced Initial Alert Annunciation Level

[V2 10176] The System **shall** provide a "pre-alert" for auditory annunciations whereby the same alarm is annunciated 10dB lower than its final calibrated level.

[Rationale: The pre-alert is intended to prevent a "startle effect" through a reduced initial onset as shown in Figure 10.3.1-1—Example Alert Waveform. The first iteration of the alarm is 10 decibels (-10 dB) below the full alarm level. Successive iterations are at the full alarm level.]

Table 10.3-1—Alert Type and Annunciation Table

	Priority	Visual Annunciation	Auditory Annunciation
Emergency – Fire Specifically identified life threatening warning event that requires immediate action.	1	Flashing Red	Repeat sequence a), b), and c) until terminated. a. Siren: square wave frequency modulated over a period of 5 s from 650 Hz – 1,500 Hz – 650 Hz; followed by: b. "Emergency Fire *location,* Fire *location*", followed by repeated language noted in "c". c. "Emergency Fire *location,* Fire *location*" where *location* is (e.g., "Vehicle A", "Module B") Silent intervals are to separate message segments (e.g., 200 ms between tone and speech). *Notes: 1, 2*
Emergency – Other than fire (e.g., pressure loss/toxic atmosphere) Specifically identified life threatening warning event that	2	Flashing Red	Repeat sequence a), b), and c) until terminated. a. Klaxon: 2,560 Hz tone, 2.1 ms on, 1.6 ms off, mixed with 256 Hz tone. Two digital pulse trains shall be logically OR'ed and the DC component removed. The first pulse train shall be a 50% duty cycle square wave at 2,560 Hz which is enabled for 2.1 ms and set to logic "0" for 1.6 ms. The second pulse train shall be a 50% duty cycle square wave at 256 Hz which is enabled for 210 ms and set to logic "0" for 70 ms. Sequence contains 4

	Priority	Visual Annunciation	Auditory Annunciation
requires immediate action.			iterations of 280 ms on-off pulse (210 ms ON, 70 ms OFF), followed by 280 ms silence. This sequence is, repeated 2 times, followed by: b. “Emergency condition location condition location”, followed by repeated language noted in “c”. c. “Emergency condition location condition location” where condition is (e.g., “Rapid Depress” or “Toxic Atmosphere”) where location is (e.g., “Vehicle A”, “Module B”) Silent intervals are to separate message segments (e.g., 200 ms between tone and speech. *Note: 2*
Warning Event that requires immediate action because it has the potential to become a life/mission threat.	3	Red	Repeat sequence a), b), and c) until terminated. a. Alternating tone (square wave), 400 Hz and 1,024 Hz at a 2.5 Hz modulation rate (400 Hz for 0.4 s then 1,024 Hz for 0.4 s, total 0.8 s); sequence contains two pairs of alternating square wave tones with total 1.6 s duration; sequence followed by 1 s silent interval; repeats 2 times b. “Warning warning message, location warning message location” c. “Warning warning message, location warning message location” where *warning message* is brief descriptive fault message (e.g., “Main Bus Fail”, “Radiation”) where *location* is (e.g., “Vehicle A”, “Module B”) Note that the message and location are optional. *Notes: 2*
Caution Event that needs attention, but not immediate action.	4	Yellow	Continuous tone triangle wave (odd harmonics at amplitude reciprocal to harmonic number) 512 Hz of duration 1 s. Subsequent repetitions consist of 1 s of silent interval followed by the 1 s tone; repeat until terminated. Note that this is a tone-only alert. *Notes: 2*
Advisory Message describing a routine event, situation, or action, or an off-nominal event that does not meet the criteria for a Caution.	5	Blue	The optional advisory tone consists of two iterations of a 900 Hz sine wave with an intervening silence. The total duration is 318 ms, and does not repeat (i.e., the advisory tone is self-terminating). The components of the tone are: 900 Hz sine wave, duration 106 ms; followed by 106 ms silence; followed by 106 ms 900 Hz sine wave. The amplitude of the sine wave does not vary when it is sounded Note that this is a tone-only alert, to be selectively applied. The advisory tone can be silenced for sleep and for crew-designated periods of time.

Notes:
1. *This siren is based on the standard ‘wail’ siren used by law enforcement that mimics historical ‘wind-up’ sirens. Frequencies have been adjusted to conform to recommended practice "Emergency Vehicle Sirens-SAE J1849 August 1995", Society of Automotive Engineers (SAE).*
2. *Rather than sounding continuously, the alarms have silent intervals in between each sequence to aid problem solving under high-stress conditions. The lower the priority of the alarm, the longer the ‘inter-burst silent interval’ (ranges from 2 – 4 s).*

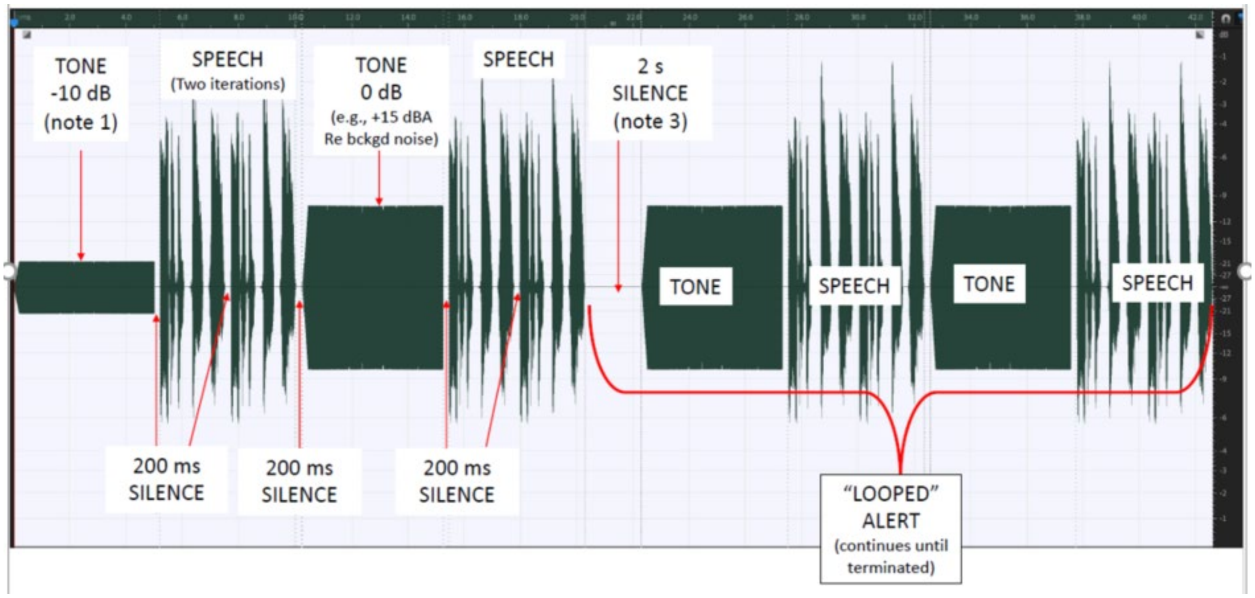


Figure 10.3-1—Example Alert Waveform

Figure 10.3.1-1—Example Alert Waveform diagram shows basic structure of alerts. The first iteration of the alarm is 10 decibels (-10 dB) below the full alarm level. Successive iterations are at the full alarm level. The buffer plays initially from time 0 to time t2; and then repeats from the loop start point until terminated.

10.3.4 Parameter Notifications

[V2 10115] The system **shall** notify the human operators if the selected system parameters are outside of tolerance.

[Rationale: A parameter is a defined value that an automatic control system is designed to maintain and include but are not limited to: high and low absolute set-points, deviation, rate of change, command disagreement, calculated, bit-pattern bit-mapped, controller output, system diagnostic, instrument diagnostic, bad measurement, statistical process control, common (group), or others. Human operators may be able to select parameters in an automatic control system. If a parameter is attempted to be changed to one that is outside of system tolerance, the system will provide consequence analysis and consequence guidance to the human operator that a change has been attempted that puts parameters outside of a tolerance or safe setting. The consequence alert acts as a check to verify that the human operator intentionally selected that change and informs them that there is a consequential impact or hazard associated with a parameter set to this range.]

10.3.5 Alert Signal Enable

[V2 10154] The system **shall** allow alert functions to be enabled by human operator.

[Rationale: Alert functions may be inhibited, shelved, or suppressed when required; when the reason for the inhibition, shelving, or suppression is no longer valid, the human operators must have a means to enable the alert function.]

10.3.6 Alert Signal Inhibit

[V2 10155] The system **shall** allow the human operator to inhibit alert functions that are Out-of-Service (OoSVC).

[Rationale: An inhibited alert function is no longer monitored for system changes and, as a result, will not be visually or audibly annunciated or logged as an event (e.g., repeated false alarms due to a sensor issue). Long-term alert inhibition is placing the alert function in an out-of-service state with the intention of not enabling the alert function in the near future. Alert inhibition is a long-term strategy for preventing nuisance alerts when equipment or systems are off-line for an extended period, or the alert function is no longer required or relevant. All alert functions must be enabled unless they are inhibited (shelved or out-of-service (OoSVC)) in accordance with a defined, implemented, and controlled inhibition methodology. The main difference between shelving and inhibiting an alert function is that a shelved (temporary) alert function will automatically return to service after the expiration of the shelving period and an inhibited alert function must be manually enabled by a human operator.]

10.3.7 Alert Inhibit Audit

[V2 10156] The system **shall** perform an audit and report all alerts that are in inhibited status to the human operators.

[Rationale: When an alert is inhibited, an alert signal will not be generated and sent to a human operator if the conditions precedent which give rise to the alert occur. If an alert is inhibited and human operators forget to reenable it, a hazard may not be detected. As a memory aid, the system must remind the human operators on a periodic basis of which alerts are inhibited so that a decision can be made to continue the inhibit or reenable the alert.]

10.3.8 Alert Signal Suppress

[V2 10177] The system **shall** allow the human operator to suppress the audio and visual alert annunciations.

[Rationale: Suppression of an alert temporarily prevents the visual and auditory annunciation. Text alert messages will still display, and alert events will still be logged. Alert Suppression is used when crew does not need to be alerted to an event but the event still needs to be recorded.]

10.3.9 Manual Activation of Emergency Responses

[V2 10178] The system **shall** provide manual activation of emergency responses that is independent of display function.

[Rationale: The crew must have the ability to manually activate automated responses to emergency events in the case they directly observe and event that is not detected by the System. For emergency events, this capability needs to be independent of a display function, such as a fixed button on a panel.]

10.3.10 Alert Silencing

[V2 10116] The system **shall** provide a manual silencing feature for active audio annunciations.

[Rationale: The capability to manually silence any alarm is to be provided to the crew. Requirements are to prescribe a method of manual silencing that is intuitive, achievable from different locations within the cabin and during different flight phases, and consistent with any other manual silencing mechanisms.]

10.3.11 Crew Test for Annunciation Failures

[V2 10117] The system **shall** test for a failure of the visual and auditory annunciators upon crew request.

[Rationale: A mechanism is to be provided to allow the crew to independently test for a failure of the visual or auditory annunciation system. The mechanism is to consist of a control to initiate the test and some type of display to provide the results for the visual and auditory portions of the system.]

10.3.12 Auditory Alert Frequency

[V2 10058] Frequency content of auditory alerts **shall** correspond to maximal human sensitivity (200 Hz to 4 kHz).

[Rationale: Auditory alarms are to use frequencies that are appropriate for human hearing. Using frequencies below or above those appropriate for human hearing makes auditory displays inaudible for the crew.]

10.3.13 Alert Sound Level

[V2 10056] The system **shall** produce non-speech auditory annunciations with an SPL that meets at least one of the following criteria:

a. Using measurements of A-weighted sound levels (ISO 7731:2003(E), Ergonomics – Danger signals for public and work areas – Auditory danger signals, method a in section 5.2.2.1), the difference between the two A-weighted SPLs of the signal and the ambient noise is greater than 15 dBA ($L_{S,A}$ to $L_{N,A}$ > 15 dBA). This method must be used for alarms intended to wake sleeping crewmembers, with the loudspeaker alarm volume adjusted to its minimum setting.

b. Using measurements of octave band SPLs (ISO 7731:2003(E), method b in section 5.2.3.1), the SPL of the signal in one or more octave bands is greater than the effective masked threshold by at least 10 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,oct to Lti,oct > 10 dB).

c. Using measurements of 1/3-octave band SPLs (ISO 7731:2003(E), method c in section 5.2.3.2), the SPL of the signal in one or more 1/3-octave bands is greater than the effective masked threshold by 13 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,1/3oct to LTi,1/3oct > 13 dB).

[Rationale: To get the attention of the crew, alarms are to be louder than the background noise. The masking threshold is the SPL of a sound one needs to hear in the presence of a masker signal. Having the audio displays 13 dB above the masked threshold ensures that the crew can hear them, regardless of the background noise. Units of measure noted below can be found in Appendix B.]

10.4 Displays and Controls

10.4.1 Display and Control Relationships

10.4.1.1 Display and Control Grouping

[V2 10032] The system **shall** provide displays and controls whose relationships are logical, explicit, and/or grouped according to purpose, function, or sequence.

[Rationale: This requirement is intended to encourage the design of a layout that optimizes operations to help ensure that displays and controls are easily accessible when used together. The relationship between displays and controls needs to be intuitive and obvious by relative location, color coding, or labeling. The most important or critical displays and controls are to be located in the most prominent noticeable locations and be quickly accessible. This helps ensure quick processing and reaction times. Controls with similar functions are to have similar properties throughout the system, to reduce the time necessary to find and operate the control. Criticality and grouping are determined through a detailed task analysis.]

10.4.1.2 Display and Control Movement Compatibility

[V2 10034] Displays **shall** be compatible with control movement and the resulting system response as defined in Table 10.4-1—Hardware and Software Controls.

[Rationale: Control-display compatibility is a widely used design principle to help ensure the relation between input direction and system responses is intuitive and easy to perceive. This helps ensure that when a control is used, system response is easy to link and conforms to crew expectations (e.g., control motion to the right is compatible with clockwise roll, right turn, and increase in volume). Operator confusion may result if system responses are not compatible with

input directions. If displays are overlaid on a visual (camera or direct view) scene, control movement is relative to this point of view.]

Table 10.4-1—Hardware and Software Controls

Device	Direction of Movement and Result
Knobs:	
Continuous and discrete position rotary	Turn clockwise with hand or fingers – turn function on, increase value, move discrete cursor right, move displayed page left Turn counterclockwise with hand or fingers – turn function off, decrease value, move discrete cursor left, move displayed page right
Ganged	Turn each individual knob clockwise with hand or fingers – turn function on, increase value, move discrete cursor right, move displayed page left Turn each individual knob counterclockwise with hand or fingers – turn function off, decrease value, move discrete cursor left, move displayed page right
Thumbwheels or scroll wheels *(operated by brushing/turning the edge of the wheel):*	
Vertical wheel orientation	Move thumbwheel/scroll wheel edge forward with thumb or finger – turn function on, increase value, move a discrete cursor up, move displayed page down Move thumbwheel/scroll wheel edge backward with thumb or finger – turn function off, decrease value, move a discrete cursor down, move displayed page up
Horizontal wheel orientation	Move thumbwheel/scroll wheel edge right with thumb or finger – turn function on, increase value, move a discrete cursor right, move displayed page left Move thumbwheel/scroll wheel edge left with thumb or finger – turn function off, decrease value, move a discrete cursor left, move displayed page right
Handwheels (operated by grasping the wheel's perimeter and turning) Note: Excludes valve wheels	Rotate handwheel clockwise with hand – turn function on, increase the value, move discrete cursor right, move displayed page left Rotate handwheel counterclockwise with hand – turn function off, decrease value, move discrete cursor left, move displayed page right
Pedals	Apply pressure to pedal with foot – turn function on, engage action, increase value. Reduce pressure to pedal with foot – turn function off, disengage action, decrease value
Momentary pushbuttons	Press and release to activate object or select menu item Press to activate function; release to deactivate function
Rocker switches:	
Vertical rocker orientation	Depress upper wing with finger – turn function on, increase value, move discrete cursor up, move displayed page down Depress lower wing with finger – turn function off, decrease value, move discrete cursor down, move displayed page down
Horizontal switch orientation	Depress right wing with finger – turn function on, increase value, move discrete cursor right, move displayed page left Depress left wing with finger – turn function off, decrease value, move discrete cursor left, move displayed page right
Push-pull controls	Pull control with hand – turn function on Push control with hand – turn function off

Device	Direction of Movement and Result
Slide/toggle switches:	
Vertical switch orientation	Slide/flip switch forward with fingers – turn function on or increase value Slide/flip switch backward with fingers – turn function off or decrease value
Horizontal switch orientation	Slide/flip switch right with fingers – turn function on or increase value Slide/flip switch left with fingers – turn function off or decrease value
Continuous cursor control devices (joystick, mouse, trackball, etc.)	Move device forward with hand – cursor moves up, displayed page moves down Move device backward with hand – cursor moves down, displayed page moves up Move device left with hand – cursor moves left, displayed page moves right Move device right with hand – cursor moves right, displayed page moves left Move device diagonally with hand in any direction – cursor moves diagonally in the same direction as the device's movement, displayed page moves diagonally opposite
Discrete cursor control devices (arrow keys, castle switches)	Press/deflect up key, switch, or button with finger – cursor moves up, displayed page moves down Press/deflect down key, switch, or button with finger – cursor moves down, displayed page moves up Press/deflect right key, switch, or button with finger – cursor moves right, displayed page moves left Press/deflect left key, switch, or button with finger – cursor moves left, displayed page moves right (If diagonal capability exists) Press/deflect key, switch, or button diagonally with hand in any direction – cursor moves diagonally in the same direction as the device's movement; displayed page moves diagonally opposite
Rotational Hand Controller (RHC)	Pivot controller forward – pitch vehicle down Pivot controller backward – pitch vehicle up Pivot controller right – roll vehicle right Pivot controller left – roll vehicle left Rotate control clockwise with hand – yaw vehicle right Rotate control counterclockwise with hand – yaw vehicle left
Translational Hand Controller (THC)	Push in on control with hand – move vehicle forward Pull out on control with hand – move vehicle backward Push right on control with hand –move vehicle to the right Push left on control with hand – move vehicle to the left Push up on the control with hand – move vehicle up Push down on the control with hand – move vehicle down

10.4.2 Displays

10.4.2.1 Simultaneous Display of Critical Information

[V2 10037] The system **shall** provide the display area to simultaneously present all critical task information required within the operator's field of regard.

[Rationale: To ensure that critical tasks can be performed quickly, easily, and accurately, especially during critical mission phases, it is important to avoid scrolling or switching among several display pages and to avoid excessive head or body movement by the crewmember to view several displays. Criticality and critical task information is determined through a detailed task analysis.]

10.4.2.2 Color Coding Redundancy

[V2 10045] The system **shall** provide an additional cue when color is issued to convey meaning for critical information or for a critical task.

[Rationale: Redundant coding is required to accommodate the variability in people's capability to see color under different lighting conditions and to increase the saliency of identification markings. Redundant cues can include labels, icons, and speech messages.]

10.4.2.3 Measurement Units

[V2 10046] The system **shall** use consistent units of measure that are displayed for each numerical value, or for each group of numeric values where the units are the same.

[Rationale: The use of consistent units of measure across a system minimizes crew training and the potential for conversion errors by crew and ground personnel, which can impact crew and vehicle safety. Measurement units are to be identifiable with the correct magnitude and scale. This ensures correct decision making when comparing or using these units in some other way.]

10.4.2.4 Visual Display Parameters

[V2 10048] The system **shall** provide IVA displays that meet the visual display requirements in Table 10.4-2—Visual Display Parameters.

[Rationale: Legibility of displayed information is important for the timely and accurate processing of information. To ensure legibility and visual quality, displays are to have sufficient spatial and temporal resolution, brightness, luminance contrast, and color gamut, taking into account the ambient illumination, glare, reflections, vibration, and distance, position, and orientation of the display relative to the crewmember.]

Table 10.4-2—Visual Display Parameters

Metric	Minimum	Maximum	Context	Notes
Peak white luminance	>100 cd/m^2	--	Emissive displays	400 cd/m^2 or higher preferred
Ambient contrast ratio	100:1	--		1000:1 or higher preferred
Color gamut area	0.17	--	Color displays	Fraction of CIE 1976 u'v' chromaticity space
Viewing angle	-/+45 deg	as defined by task analysis		Four-point viewing angle (left, right, up, down), contrast and color gamut criteria met
Spatial resolution	32 pixels/deg	--	Image and video displays	64 pixels/deg or higher preferred
Frame rate	60 Hz	--	Video displays	60Hz is an absolute minimum to avoid flicker, but 90Hz should be the minimum for any display used for active control
Moving edge blur	--	15 ms		Using metric GET (preferable) or BET; use average of five equal lightness levels, including white and black
Number of colors	2^{24} (1,627,716)	--	Image and video displays	
	2^{12} (4,096)	--	Text and graphics displays	
Number of gray levels	2^{8} (256)	--	B/W image and video displays	
Except where noted, metrics are as defined as in International Committee on Display Metrology (ICDM), Display Measurement Standard (DMS 1.0), or Video Electronics Standards Association (VESA) Flat Panel Display Measurements (FPDM 2.0). Further details on metrics may be found in chapter 10, Crew Interfaces, of the HIDH.				

10.4.2.5 Indicator Light Characteristics

[V2 10201] The system **shall** implement indicator lights that meet the characteristics shown in Table 10.4-3—Indicator Light Characteristics.

[Rationale: This requirement promotes consistency across indicators and the use of color for alerts, reducing the risk of misinterpretation and error. Care must be taken to ensure colors are distinguishable (e.g., yellow is not confusable with green).]

Table 10.4-3—Indicator Light Characteristics

Type	Meaning
Flashing Red	Emergency
Red	Warning, Failed
Yellow	Caution, Off-nominal State, Trip
Green	Power, On, Enabled, Good State

10.4.3 Labels

10.4.3.1 Label Provision

[V2 10060] The system **shall** provide labels for the crew to identify items, interpret and follow nominal and contingency procedures, and avoid hazards.

[Rationale: Crew interface items are to have identifiers (labels) to aid in crew training and error-free operation. Labels reduce memory load and improve accuracy of tasks. This includes identification of emergency equipment and procedures. The Labeling Plan identifies which interfaces require labels.]

10.4.3.2 Label Location

[V2 10063] The system **shall** provide labels that are positioned on or directly adjacent to the item they are labeling.

[Rationale: Labels that are placed far from items they intend to label can result in the crew missing their association or misidentifying items. This can slow down task performance and may cause errors.]

10.4.3.3 Label Font Height

[V2 10066] The system **shall** provide labels that have a minimum font height of 12-point or 0.4 degrees in expected operating positions.

[Rationale: Labels are to use a large enough font size to ensure legibility. Small fonts can make labels difficult to perceive by the crew, consequently increasing the time needed for item identification. Font height in degrees refers to the angle subtended at the eye by the height of an uppercase letter in the font. The font height given is a minimum. The font may have to be larger for readability when taking into account the ambient illumination, glare, reflections, vibration, position, and orientation of the label relative to the crew.]

10.4.4 Controls

10.4.4.1 Out-of-View Control Identification

[V2 10068] Controls that are intended for out-of-view operation **shall** be spatially or tactually distinct from one another.

[Rationale: When the crew inadvertently operates the wrong control, serious errors can result. Controls designed to be out of view while being operated are to be spaced or shaped/textured such that the control can be identified with a pressurized gloved hand without line of sight. This would include controls for vehicle operation, as well as other controls (e.g., seat positioning). It

has been shown that human operators can use simple tactile coding to reliably distinguish between items.]

10.4.4.2 Hazardous Control Coding

[V2 10069] The system **shall** provide coding for hazardous or irreversible controls that are distinguishable from non-emergency controls.

[Rationale: Coding for emergency controls allows the operator to distinguish them from other controls. This will help the operator react faster in an emergency situation. It has been shown that operators react more quickly to simple coding such as colors and pictures than they do to written labels. A task analysis defines the list of emergency controls. Guidance on the development of hazard, caution and warning, and emergency use labels and coding can be found in Section 4.13 of JSC 65995, Commercial Human Systems Integration Processes (CHSIP).]

10.4.4.3 Control Spacing

[V2 10070] The system **shall** provide spacing between IVA controls that meets the criteria in Table 10.4-4—Control Spacing.

[Rationale: The spacing between controls is to be appropriate for the type of control and operating condition. Inadequate separation can cause errors during control operation. Preferred separations are to be used unless space does not allow, then controls must be at least the minimum distance apart or separated by guards. Push buttons are used if a control is needed for momentary contact or activation. They are not used when the status of a function must be indicated by position of its control. Knobs are used if low force or precise adjustment of a continuous variable is required. Other types of controls and specifications not listed in the table can be found in the Human Integration Design Handbook (HIDH) or HF-STD-001B FAA Human Factors Design Standard.]

Table 10.4-4—Control Spacing

Push Buttons					
		Single Finger	Single Finder Sequential	Different Fingers	Thumb or Palm
Bare Handed	Minimum	13 mm (0.5in)	6 mm (0.25 in)	6 mm (0.25 in)	25 mm (1 in)
	Preferred	50 mm (2.0in)	13 mm (0.5 in)	13mm (0.5 in)	150 mm (6 in)
Knobs					
		One Hand Individually		Two Hands Simultaneously	
Bare Handed	Minimum	25 mm (1 in)		50 mm (2.0 in)	
	Preferred	50 mm (2in)		125 mm (5.0 in)	

10.4.4.4 Connector Spacing

[V2 10157] The system **shall** provide spacing between IVA connecters that is at least:

a. 25 mm (1 in) if operated with bare fingers,

b. 32 mm (1.25 in) if operated with unpressurized gloved fingers,

c. 64 mm (2.5 in) if must be "gripped firmly” with multiple fingers.

[Rationale: A connector is a piece of hardware that joins or attaches lines or cables to other lines or cables or to units of equipment. The term is used rather loosely to refer to either of the two parts that mate with each other and to the plug that mates with a receptacle. Inadequate separation between connectors can prevent all users from successfully mating or demating connectors. Distance between connectors is measured from the outermost portion of the connector, including any shell, clamp, cover, or shield that exists.]

10.4.4.5 Control Operation Supports and Restraints

[V2 10073] The system **shall** provide body or limb supports and restraints that enable accurate crew control of applicable interfaces and prevent inadvertent control inputs during expected gravity, acceleration, and vibration conditions.

[Rationale: During expected gravity acceleration and vibration conditions, the accuracy of gross limb movements is compromised, and support of the operator limbs is required for control tasks. Control action under these conditions is to be limited to hand and wrist motions alone.]

10.4.4.6 Moderate-g Control Configuration

[V2 10158] The system **shall** place controls used during accelerations between 2g and 3g so that the operator can make control inputs via hand/wrist movements and forward reached within +/- 30-degree cone.

[Rationale: Between 2g and 3g, controls must be operable by a restrained crewmember. In a study of reaches under Gx loading with veteran astronauts and aviators as subjects, suited subjects on average exhibited little impact at 2g but did show a 6% reduction in maximum forward reach displacement at 3g (Schafer & Bagian, Aviation, Space, and Environmental Medicine, 64: 979, 1993). Hence, between 2g and 3g, even with highly motivated and trained subjects, reaches will begin to show errors above 2g, and so control actions are to be limited to hand/wrist motions or forward arm movements within a +/- 30-degree cone (apex at the shoulder joint, aligned with the axis of acceleration). For tasks requiring rapid response times or for deconditioned crew, a more conservative approach with controls placed to minimize reach - allows for an improved crew ability to operate the control. Awkward shoulder/elbow postures, which could result from reaches to displays/interfaces at close distances, increase fatigue and errors resulting in high crew workloads that could exceed workload requirements. Additionally, proper arm/wrist support are to be provided such that operation of any hand controller is not hampered by g-loading.]

10.4.4.7 High-g Control Configuration

[V2 10159] The system **shall** place controls during accelerations above 3g so that the operator can make control inputs via hand/wrist movements without reaching.

[Rationale: Above 3 g, controls must be operable by a restrained crewmember and the accuracy of gross limb movements is compromised. Therefore, control action under these conditions is to be limited to hand and wrist motions alone. Arms/legs will require proper support and/or restraint to allow for accurate control input during elevated g conditions and to prevent inadvertent control inputs during high-g nominal and abort scenarios. In a study of reaches under Gx loading with veteran astronauts and aviators as suited subjects, there was a 6% reduction in forward reach displacement at 3 g, 18% at 4 g, and 32% at 5 g (Schafer & Bagian, Aviation, Space, and Environmental Medicine, 64: 979, 1993). Proper arm/wrist support are to be provided such that operation of any hand controller is not hampered by g-loading.]

10.4.4.8 Manual Piloting Control Latency

[V2 10076] The system **shall** provide controls for the execution of manual piloting such that latencies will be less than 100ms for high gain tasks and less than 200ms for low gain piloting tasks.

[Rationale: State changes associated with the operation of a control are to have minimal time delays such that handling qualities of the vehicle are not negatively impacted. If the inception of a controller and the pilot's observation of its system response occur with a significant latency, it is difficult to identify whether the operation of the control had the intended effect within sufficient time constraints, leading to adverse handling qualities and possibilities of adverse outcomes such as pilot induced oscillation. For piloting tasks, such lags must not result in pilot induced oscillation and support handling qualities as required by [V2 10004] Handling Qualities. High gain tasks are those for which temporal demands and task urgency are key drivers of task success or failure (such as lunar landing), while low gain tasks are those which place lower temporal demands on the crew (such as RPODU). The acceptable levels of latency presented in this requirement are consistent with MIL-STD-1797A – Flying Qualities of Piloted Aircraft, and as described by Effect of Time Delay on Flying Qualities: An Update (R.E. Smith and S.K. Sarrafian, Journal of Guidance, Control, and Dynamics, Vol 9, No. 5. 1986).]

10.4.4.9 Manual Piloting Control Latency Variability

[V2 10160] The system **shall** provide controls for the execution of manual piloting such that latencies have a minimum variability.

[Rationale: If the latencies (time delays) that exist are not consistent and are highly variable during the execution of a task, it can be extremely difficult for crew to mitigate or adapt to the effects of such delays as the inconsistency makes adaptation almost impossible.]

10.4.4.10 Control Resistive Force

[V2 10077] Control resistive force **shall** prevent unintended drifting or changing of position.

[Rationale: Controls must resist drifting or changing of position due to normal operational forces such as gravity on planetary surfaces or g-loading during maneuvering or station keeping for vehicles and space based-platforms.]

10.4.4.11 Detent Controls

[V2 10078] The system **shall** provide detent controls when control movements occur in discrete steps.

[Rationale: Mechanisms that provide control feedback to crewmembers are to be based on the amount of the movement applied to the control. This is usually provided using auditory and haptic feedback.]

10.4.4.12 Stops Controls

[V2 10079] The system **shall** provide stops at the beginning and end of a range of control positions, if the control is not required to be operated beyond the end positions or specified limits.

[Rationale: Limits within which controls can be operated are to be obvious to the crew by the provision of easy-to-perceive stops in the mechanism of the controls. Failure to include stops can result in increased operations time, as the operator may needlessly continue to turn a dial after it has reached its functional end point.]

10.5 Audio, Communication, and Video Systems

10.5.1 Audio Systems

10.5.1.1 Intelligibility of Electronically Stored Speech Messages

[V2 10052] Electronically stored speech messages from audio displays **shall** have 100% intelligibility and discriminability between the ensemble of different messages the audio display is programmed to produce (as measured under realistic background noise conditions and at locations where the display will be used).

[Rationale: Some audio displays and alarms express their messages using electronically stored speech. The consequences of misunderstanding these messages can result in lost time and possible missed or false alarms and can ultimately be a critical safety issue.]

10.5.1.2 Reverberation Time

[V2 10057] The system **shall** provide a reverberation time of less than 0.6 seconds within the 500-Hz, 1-kHz, and 2-kHz octave bands.

[Rationale: This 0.6 s reverberation time requirement limits degradation of speech intelligibility to no more than 10% for ideal signal-to-noise ratios of >30 dB or 15% for a signal-to-noise ratio of 3 dB (Harris, 1997).]

10.5.2 Communication Systems

To ensure optimal team collaboration in exploration missions, it is essential to design communication systems that provide an accurate, comprehensive, real-time understanding of the current situation and to implement tools that enable team members across the multi-team system of crew and ground to communicate and collaborate effectively. This is particularly critical when teams are operating in the presence of communication transmission delays and intermittent transmission. Communication systems process information to and from the crew and may consist of the following media: voice/audio, video, text, and data.

10.5.2.1 Communication System Design

[V2 10083] Communication systems **shall** be designed to support coordinated and collaborative distributed teamwork.

[Rationale: To ensure optimal team collaboration in exploration missions, it is essential to design communication systems that provide an accurate, comprehensive, real-time understanding of the current situation and to implement tools that enable team members across the multi-team system of crew and ground to communicate and collaborate effectively. This is particularly critical when teams are operating in the presence of communication transmission delays and intermittent transmission. Communication systems process information to and from the crew and may consist of the following media: voice, video, text, and data.]

10.5.2.2 Communication Capability

[V2 10084] The system **shall** provide the capability to send and receive communication among crewmembers, spacecraft systems, and ground systems to support crew performance, behavioral health, and safety.

[Rationale: Communication capabilities are necessary to enable information exchange to accomplish tasks efficiently, to maintain crew physical and behavioral health, and to ensure crew safety. The capability to send and receive information among crew (IVA and EVA), Earth-based mission control, orbiting vehicles, planetary habitats, extraterrestrial surface transport vehicles, robotic systems, and other systems is to be supported as required by the task analysis for the particular Design Reference Mission (DRM). Communications can include voice, text, video, telemetry, and other formats, depending on the needs as determined by a task analysis.]

10.5.2.3 Communication Speech Levels

[V2 10085] Audio communication systems **shall** allow crew to communicate with one another and with the ground at normal speech levels and with expected background SPLs.

[Rationale: When crewmembers and ground personnel use the voice communication systems, they are to be able to do so using their normal level of speech, rather than having to raise their voices to higher levels. Higher voice levels distort sounds, make speech less intelligible, and are more strenuous to keep up for longer periods.]

10.5.2.4 Speech Intelligibility

[V2 10091] For critical communications, the system **shall** ensure 90% English word recognition, using ANSI/ASA S3.2-2009, Method for Measuring the Intelligibility of Speech over Communication Systems.

[Rationale: Voice communication is to be perceived accurately. If messages are perceived with errors or low precision, important information may be missed; therefore, crew may make errors in tasks, and their safety may be jeopardized. To ensure speech intelligibility, the communication system must take into account operational parameters (including frequency, dynamic range, noise cancelling and shields, pre-emphasis, and peak clipping), appropriate background sound levels and architectural acoustical characteristics for both transmitter and receiver area, operating controls and procedures (including volume, squelch, natural language, acknowledgement feedback, and muting), and transmitter and receiver configuration (including headsets, microphones, air bone conduction, and bone conduction). Communication is optimized by considering all parameters needed for speech intelligibility. Background noise, reverberations, and other acoustic phenomena are not to interfere with crew communications. High levels of background noise can make audibility of speech difficult. High reverberations interfere with intelligibility. Procedures are to use natural language. Note: [V2 10091] Speech Intelligibility in this NASA Technical Standard is not meant to apply to speech recognition software.]

10.5.2.5 Private Audio Communication

[V2 10093] The system **shall** provide the capability for two-way private audio communication with the ground.

[Rationale: Private communication capabilities are to exist for the crewmember to discuss topics such as family, health, and medical issues with the ground in private.]

10.5.3 Video Systems

Video communications systems are communications channels designed to convey visual information such as camera video, animated graphics, and photographic images.

10.5.3.1 Video Communications Visual Quality

[V2 10094] Video communications **shall** employ digital encoding or alternate coding of equivalent visual quality.

[Rationale: The quality of the video communications is to be appropriate for correct information transfer. Bad image quality can be misinterpreted, can cause communication problems, and can increase time needed to accomplish tasks.]

10.5.3.2 Video Communications Spatial Resolution

[V2 10095] Video communications **shall** provide sufficient spatial resolution (width and height in pixels) to accomplish relevant tasks.

[Rationale: The resolution of video is to be appropriate for the task that it is intended to serve, so that errors related to artifacts of low resolution and delays in task completion are avoided.]

10.5.3.3 Video Communications Temporal Resolution

[V2 10096] Video communications **shall** provide sufficient temporal resolution (frames/s) to accomplish relevant tasks.

[Rationale: The temporal resolution of a communication is to be appropriate so as to perceive human speech, motion, and object motion through the video. Inappropriate resolution can make these more difficult or impossible, thus causing difficulties in information transfer.]

10.5.3.4 Video Communications Color and Intensity

[V2 10097] Video communications **shall** provide sufficient color and intensity levels to accomplish relevant tasks.

[Rationale: Color and intensity are to be transmitted appropriately. Inappropriate color and intensity in video communication may cause misidentification and misinterpretation of information, thus causing errors and problems in task completion.]

10.5.3.5 Video Communications Bit Rate

[V2 10098] Video communications systems **shall** support bit rates high enough to ensure that compression artifacts are as low as reasonably achievable.

[Rationale: The compression method and level used for video communication are not to introduce excessive visible artifacts. Artifacts can hinder information transfer and can cause communication difficulties.]

10.5.3.6 Audio-Visual Lag Time

[V2 10099] Communications systems that carry sound and video that are intended to be synchronized **shall** ensure that the sound program does not lead the video program by more than 15 ms or lag the video program by more than 45 ms.

[Rationale: The video and associated audio time lag can cause perceptual difficulties for the crew. When listening to human speech, even small lags between audio and video can be noticeable and disturbing.]

10.6 Automated and Robotic Systems

Automation is the use of machines or computers to perform tasks to reduce crew workload, increase productivity, or decrease risk in operations that the crew cannot safely perform. Systems are to have automated or robotic solutions that can perform tasks where (1) crew cannot respond as quickly, precisely, or repeatedly as necessary; (2) crew cannot physically complete the task; or (3) using automation/robotic solutions reduces crew risk exposure (e.g., high radiation environments, limited life support availability). Automation function needs to be designed around human roles for specific tasks, with the human operator having ultimate authority. In almost all cases, the human should remain in command, which essentially means they have the power to override or shut down the system. The allocation of responsibilities between humans and automation should seek to optimize overall integrated team performance. Design requirements are to ensure that decision support is available to crew. The human operator needs to understand why the automated system is recommending actions, and the consequences of those actions, to make an informed decision. Decision aids could also help with simulating the course of action chosen by the expert. Automated and robotic systems should have preventive/safety measures in place, such as mechanical constraints, threshold set points, automatic shutoffs, and emergency stops to ensure that they cannot negatively impact the mission, hardware, or crew health and safety. Robotic systems with internal safety checks that recognize and avoid unsafe conditions, e.g., excessive speed, force, and torque, are more likely to achieve mission success. This applies to robotic systems both inside and outside spacecrafts. For more information regarding this subject, see Chapter 10, Crew Interfaces, of the Human Integration Design Handbook (HIDH). Design requirements are to ensure that different levels of automation are available, depending on which level best suits the task/situation. While higher levels of automation can result in increased crew performance (e.g., fewer errors) and lower workload, they can also result in poorer SA and loss of crew skills (Onnasch, et al, 2014). This tradeoff should be taken into consideration when designing automated and robotic systems. Task analysis in conjunction with function allocation evaluations should determine the appropriate level of automation, and a trade analysis should be conducted. Systems are not to be so reliant on automation that human operators cannot safely recover from emergencies or operate the system manually if the automation fails. It needs to be clear whether the human operator or the system is supposed to perform a particular task at a specific time. The operators need to be able to determine and affect what level of automation the system is operating in, as well as which processes are being automated. The analysis will determine cases where alerting may be required when automation takes control from human operators or switches to a higher level of *automation. The below technical requirements do not apply when time to effect is too short to allow successful human intervention.*

10.6.1 Automation System Status Provision

[V2 10161] The automated system **shall** provide the human operator with the following information:

a. system state (e.g., position, location, hazardous condition, running, paused, faulted, completed, overridden, stopped, readiness)

b. projection of future state, including failure or decrements in performance (e.g., battery power versus traverse distance and assessment of uncertainty in projection of future state) and mode (e.g., Full/Partial/Manual/Test)

c. system health

d. configuration information (e.g., setup/input parameters, initial conditions, and terminating conditions)

[Rationale: The human operator needs to maintain situation awareness to work effectively with automation, calibrate trust in the system, and avoid errors. The operator needs access to information about system health and the projection of system state to understand how well automation is likely to perform and calibrate trust (knowing which situations can rely on automation, which situations require increased oversight by the operator, and which situations are inappropriate for automation). The operator needs to be aware of automation performance decrements or failures to be ready to resolve the situation or take over the task.]

10.6.2 Automation Mode Change Notification

[V2 10162] The system **shall** notify the human operator of mode changes of any safety-critical operations.

[Rationale: Conspicuous indication of the current mode will help prevent operators from making mode errors (i.e., taking an inappropriate action or failing to take a needed one, caused by thinking the system is in one mode when it is in another mode). Notification by displays or other means gives the operator the ability to prepare for a mode change or to adjust behavior to a new mode environment. Designers need to define the best methods to inform and notify humans before the change takes place and gain when it happens.]

10.6.3 Automation Data Availability

[V2 10163] Automated or robotic systems **shall** record and make available operational and performance data to both crew and ground support personnel.

[Rationale: Data, such as telemetry, states, modes, etc., should be saved and made available to operators both in space and on ground. Historical performance information on automated processes can aid in understanding current trends and events and help inform needed actions. Significant event data can aid in troubleshooting future issues.]

10.6.4 Automation System Responsibility Delineation

[V2 10164] Automated systems **shall** indicate whether a human operator or system is expected to perform a particular operation at a specific time.

[Rationale: A clear, salient delineation of the responsibilities of the human and the automated system is important to ensure that the operator performs the appropriate actions at the appropriate time. Transitions between automated and human operator control need to be performed under well-defined procedures that specify system state before and after the transition. Previous close calls in spaceflight operations have occurred because the human operator delayed in taking particular actions at specific times. Specific indicators will help support human-automation interaction that avoids errors of omission and commission.]

10.6.5 Automation and Robotics Override and Shut-Down Capabilities

[V2 10165] Automated or robotic systems **shall** provide the human operator the ability to safely override and shut down automated systems or subsystems.

[Rationale: The system is to allow the human operator the ability to override or shut down automated or robotic systems if it is determined that these systems present a risk, or if redirection of activities is needed. The human is to remain in ultimate control of the vehicle at all times throughout a mission. It is essential that the override or shut down capability is performed safely, i.e., avoids inadvertent harm to crew and vehicle.]

10.6.6 Automation System Configuration

[V2 10166] Automated or robotic systems **shall** provide the human operator the ability to modify system configuration within the safety and performance limits of the system.

[Rationale: In a human-automation team, the human operator must remain in control and thus needs to be able to modify automation configuration information, including setup/input parameters, initial conditions, and terminating conditions. There are some configurations that must not be allowed to be manipulated due to performance or safety considerations, which are specific to each system.]

10.6.7 Range of Control

[V2 10167] Automated or robotic systems **shall** provide the human operator with a range of control options that accommodates the expected operating conditions.

[Rationale: Automated or robotic systems are expected to be operated in different manners; for example, these highly flexible systems will be controlled directly (i.e., manual control) or commanded remotely (i.e., supervisory control). The multiple options associated with these highly flexible systems must be operable via a range of controls available to the human operator.]

10.6.8 Automation Failure Recovery

[V2 10168] The automated or robotic system **shall** enable the human operator to safely assume control of the system if a failure occurs or there is an inability to function (e.g., beyond designed ability).

[Rationale: If a failure or inability to function happens, the information provided by the system is to enable the human operator to collect confirming or exclusion evidence to decide on a safe course of action.]

10.6.9 Decision Support

[V2 10169] The automated or robotic system **shall** allow the human operator to determine when to use a decision aid and which decision aiding strategy to employ.

[Rationale: The human operator is to remain in control and has the authority to decide when and how to use decision aids. Decision aids are to provide pertinent data or information, analysis, and/or suggested solutions for continued operations. The system ultimately needs to enable the operator to make those decisions, whether or not it is the operator that acts on them.]

10.6.10 Decision Aid Clarity

[V2 10170] Decision aid systems **shall** provide explanations and rationales, and consequences of potential actions.

[Rationale: The human operator needs to understand why the automated system is recommending actions, and the consequences of those actions, to make an informed decision without significantly disrupting the operator's task. This is key to maintaining situation awareness, as well as calibrating trust. Decision aids are key to problem diagnosis, and hence, automation transparency is an essential attribute for these systems. Decision aids can also help with simulating the course of action chosen by the expert. The aid can help identify weaknesses in the plan and provide improvement options. When developing decision aids, it is important to base concepts on human factors principles, while considering the flow of information and the level of detail that it needs to contain.]

10.6.11 Decision Aid Limitation Notification

[V2 10171] Decision aids **shall** notify the human operator when a problem or situation is beyond the aid’s capability.

[Rationale: The human operator needs to be made aware when a decision aid is unable to assist with a decision due to lack of information or limitations in design so that information can be provided, or other avenues can be explored in a timely manner (e.g., call ground).]

10.6.12 Automation Safe Mode

[V2 10172] The automated or robotic system **shall** take protective action (e.g., avoidance maneuver, protective stop) or request that the operator safely take control if the system's operational safety threshold is exceeded.

[Rationale: Protective actions include avoidance maneuvers, protective stops, and "return home" if the human operator can no longer communicate or command the system. The transition to operator control needs to occur safely and minimize harm to the operator and vehicle.]

10.6.13 Safety Default

[V2 10173] The automated or robotic system **shall** maintain safe operations if the human operator does not assume control when requested.

[Rationale: In a failed transfer of control from the automated system to the human, the automated system experiencing degraded performance must take appropriate measures to remain in a safe state, including alerting the operator of the degraded state and transfer of control.]

10.6.14 System Initiation

[V2 10174] Autonomous robotic systems **shall** be initiated only by human operators, including restart after an emergency or protective stop.

[Rationale: The human operator is to remain in control and must authorize a system restart after an emergency or protective stop.]

11. SPACESUITS

Section 11 includes requirements that are specific to spacesuits and suited operations. Spacesuits provide a self-contained habitable atmosphere that sustains human life and meets crew health, safety, and performance needs throughout suited mission durations. Suited activities (EVA, LEA or IVA) are an essential part of many human space missions. Unless otherwise identified as being applicable to EVA, IVA or LEA spacesuits, requirements in this section will be considered applicable to all three. For the purposes of this NASA Technical Standard, the following definitions are used for LEA Spacesuit Systems and EVA Spacesuit Systems:

- *LEA Spacesuit System Definition: Any spacesuit system designed without an independent life support system and primarily for use during launch, entry, and abort phases of spaceflight, primarily to protect against toxic exposure, ebullism, hypoxia, and decompression sickness in the event of an unplanned cabin depressurization or toxic release into the cabin. It may also be worn during other dynamic phases of flight such as rendezvous and docking during which there is an increased risk of cabin depressurization due to cabin leaks. The duration for which LEA spacesuits are designed to operate will depend on mission scenarios and may range from a few hours to several days per use.*

- *EVA Spacesuit System Definition: Any spacesuit system designed to allow astronauts to perform tasks outside of a spacecraft or habitat in microgravity or partial gravity. Performance of spaceflight EVA consists of placing a human in a micro-environment that provides all the life support, nutrition, hydration, waste, and consumables management function of an actual space vehicle, while allowing crewmembers to perform mission tasks. EVA spacesuits are designed to be used for durations of less than a day due to potential human and suit system constraints. This includes all suited phases (e.g., prebreathe, leak checks, airlock/cabin/suitport depress).*

As described in section 3.1 and many other requirements in this NASA Technical Standard are also intended to be applicable to spacesuits; section 11 is a subset of requirements that are uniquely applicable to spacesuits and suited operations. For planetary exploration missions, crew access to the planetary surface within an EVA suit is fundamental to mission success and safety. Suited activities allow many aspects of mission science, exploration, and maintenance. Compliance with the requirements stated here is crucial to the health, safety, and performance of the suited crew. Consult NASA-STD-3001, Volume 1, for EVA health and medical requirements. Consult EHP-10028, Extravehicular Activity and Human Surface Mobility (EHP) Exploration EVA (xEVA) System Compatibility Standards, for detailed guidance and constraints primarily concerned with safety, design of EVA support equipment, layout of EVA translation paths, and human-machine interfaces for crew operation. It is important for vehicle designers to understand and account for the interfaces between vehicle systems and spacesuits. These human system requirements should be reviewed for consideration of the suit-to-system interface.

11.1 Suit Design and Operations

11.1.1 Suited Donning and Doffing

[V2 11001] The system **shall** accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations.

[Rationale: Spacesuit donning, and doffing is a non-productive activity. Additionally, tedious and difficult tasks are more prone to neglect and human error. Finally, rapid donning and doffing must be done correctly in the right sequence and can be critical in any circumstance, including an emergency. System developers need to consider total system design and human accommodation, including emergency scenarios, assess donning task times, and evaluate features such as unassisted donning.]

11.1.2 Suit Materials Compatibility

[V2 11125] Pharmaceuticals, topical treatments and cleaning materials **shall** be compatible with suit materials (internally and externally).

[Rationale: The suit materials selected are expected to be exposed to medications used by the crewmember (i.e., topical medications) that need to be assessed for potential interactions with the materials and atmospheric filtration. This compatibility is to be considered when medications are selected for use by the crew and as supplied by the program in [V1 3004] In-Mission Medical Care. Additionally, the cleaning materials expected to be used will be assessed as stated in [V2 7083] Cleaning Materials.]

11.1.3 Suit Materials Cleanability

[V2 11126] The suit materials (internally and externally) **shall** be compatible with the expected cleaning materials and methods.

[Rationale: During the life of the suit, crew are typically expected to do regular maintenance or cleaning of the suit after each use. This cleaning may require removal of particulates from the exposure during an EVA or potentially an event where the suit was exposed to harmful contaminants. Cleaning materials selected are expected to be evaluated per [V2 7083] Cleaning Materials and any other methods as determined by the program. The suit materials selected are to consider the cleaning methods to be used (internally and externally), metabolic wastes (sweat, urine, etc.) and topical medications applied. The requirement for the medical kit supplied [V1 3004] In-Mission Medical Care will need to consider the design and materials supplied to the crew to prevent any restrictions to medication use when it is needed by a crew member wearing a suit, like during an EVA.]

11.1.4 Suit Environment

11.1.4.1 Suit Pressure Set-Points

[V2 11006] The suit **shall** provide the capability for the crewmember to select discrete suit pressure set-points within the suit operating pressure ranges during pressurized and unpressurized suited operations.

[Rationale: To implement operational concepts possible in a variable pressure suit, the crewmember is to be able to select the desired discrete pressure setting.]

11.1.4.2 Suit Equilibrium Pressure

[V2 11007] Suits **shall** maintain pressure within 1.72 kPa (0.25 psi) after the suit has achieved an equilibrium pressure for a set-point.

[Rationale: Maintaining a constant pressure level after a set-point has been reached is important to protect the crewmember from discomfort in body cavities and sinuses, especially in the ear. Maintaining a constant pressure level is intended to protect the crewmember in the pressurized suit. Because of the relatively small total pressure volume in the suit, it is important that the pressurized-suited crewmember is exposed to a pressure set-point that is constant (unchanging). Excess fluctuations in suit pressure cause pressurized-suited crewmembers to constantly re-equilibrate pressure in body cavities and sinuses, which increases the likelihood of pressure-induced discomfort in these areas.]

11.1.4.3 Continuous Noise in Spacesuits

[V2 11009] Suits **shall** limit suit-induced continuous noise exposure at the ear to NC-50 or below without the use of auxiliary hearing protection.

[Rationale: This requirement limits noise levels within the suit to allow for adequate voice communications and comfort. This requirement does not apply to alarms, communications, or to any noise experienced during maintenance activities. The noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement unless they are included in the nominal suit configuration, i.e., not added to meet this requirement. Consideration is to be given to protect the frequencies necessary for communications transmission from ambient or suit-generated noise.]

11.1.4.4 EVA Suit Radiation Monitoring

[V2 11010] The suit **shall** provide or accommodate radiation monitoring and alerting functions to allow the crew to take appropriate actions.

[Rationale: Radiation monitors are to provide primary data for controlling crewmember radiation exposures during EVA. The current exposure limits for deterministic effects (short-term

exposure limits) are specified in NASA–STD-3001, Volume 1; and to demonstrate compliance, radiation monitoring is required.]

11.1.4.5 Suited Crewmember Heat Storage

[V2 11011] The system **shall** prevent the energy stored by each crewmember during nominal suited operations from exceeding the limits defined by the range 3.0 kJ/kg (1.3 Btu/lb) > ΔQ stored > -1.9 kJ/kg (-0.8 Btu/lb), where ΔQ stored is calculated using the 41 Node Man or Wissler model.

[Rationale: This requirement applies to nominal microgravity EVA operations and nominal surface EVA operations. Excess heat load and accumulation may quickly reach human tolerance limits and may impair performance and health. Impairment begins when skin temperature increases greater than 1.4ºC (2.5ºF -17) (0.6ºC [1ºF -17.4]) core or if pulse is greater than 140 bpm). Increases in body core temperature may lead to associated performance decrements. Keeping the heat storage value below the performance impairment line allows the crewmember the ability to conduct complex tasks without heat-induced degradation. If the crewmember is in a suit, the heat load may increase rapidly. Supporting data from military aircrew protective ensembles suggest body temperature may increase more rapidly over time in suited crewmembers compared to those in a shirt-sleeve environment. The current change in heat storage limit is to allow nominal suited operations with crewmember metabolic rates of 528 to 2220 kJ/hr (500 to 2100 Btu/hr) without undue heat discomfort.]

11.1.5 Suit Waste Management

11.1.5.1 Suited Body Waste Management – Provision

[V2 11013] Suits **shall** provide for management of urine, feces, menses, and vomitus of suited crewmembers.

[Rationale: The total system is to be designed for body waste collection, as well as disposal of waste in the system's waste management system and cleaning of the suit for reuse. Waste management items are to be able to contain and dispose of human waste with as much containment and isolation as possible. Provisions are to be available for personal hygiene and suit cleaning.]

11.1.5.2 EVA Suit Urine Collection

[V2 11028] EVA suits **shall** be capable of collecting a total urine volume of $V_u = 0.5 + 2.24t/24$ L, where t is suited duration in hours.

[Rationale: This EVA suit requirement is separate from the LEA suit requirement below requirement [V2 11014] LEA Suit Urine Collection, to ensure that the increased EVA suit hydration (per requirement [V2 11030] EVA Suited Hydration, specifying an additional 8.1 fl oz ≈ 240 mL per hour for EVA suited operations) is a design consideration for EVA suit urine

collection. This straightforward input-output equation does not consider variables such as metabolic rate, relative humidity, or hydration, which could affect the total volume. The voided urine is to be isolated to prevent inadvertent discharge in the suit that could result in injury to a crewmember's skin or mucous membranes or damage to the suit system.]

11.1.5.3 LEA Suit Urine Collection

[V2 11014] LEA suits **shall** be capable of collecting a total urine volume of Vu = 0.5 + 2t/24 L throughout suited operations, where t is suited duration in hours.

[Rationale: This requirement allows crewmembers to eliminate liquid waste at their discretion without affecting work efficiency during suited operations. The suit is only responsible for the expected urinary output during the time that the crewmember is in the suit. The urinary collection system is to be capable of collecting all of the crewmember's output in succession, with an average void varying from 100 to 500 mL (3.4 to 16.9 fl oz). The rate of urinary delivery into the system from the body varies by sex (greater for females because of lower urethral resistance) but averages 10 to 35 mL/s (0.34 to 1.2 fl oz/s). Maximum flow rate with abdominal straining in a female may be as high as 50 mL/s (1.9 fl oz/s) for a few seconds. Output collection capacity is designed to match water input potential; the Vu equation does not consider variables such as metabolic rate, relative humidity, or hydration, which could affect total urine volume. The voided urine is to be isolated to prevent inadvertent discharge in the cabin that could result in injury to a crewmember's skin or mucous membranes or damage to equipment.]

11.1.5.4 Suit Urine Collection per Day – Contingency

[V2 11015] For contingency suited operations lasting longer than 24 hours, suits **shall** be capable of collecting and containing 1 L (33.8 fl oz) of urine per crewmember per day.

[Rationale: Urine output may be slightly greater or lower in various phases of the mission associated with g-transitions and fluid intake levels. Rarely, a single void might be as much as 1 L (33.8 fl oz), so the equipment is to be able to accommodate this maximum. Also, in the event of an unrecoverable vehicle pressure failure wherein an extended stay in the suit is used to maintain life, crewmembers are to have the capability to access fecal and urine collection systems. The voided urine is to be contained by the stowage and disposal hardware to prevent inadvertent discharge into the suit that could result in injury to the crewmember's mucous membranes or equipment.]

11.1.5.5 Suit Feces Collection per Day – Contingency

[V2 11016] During contingency suited operations, suits **shall** be capable of collecting 75 g (0.17 lb) (by mass) and 75 mL (2.5 fl oz) (by volume) of fecal matter per crewmember per day.

[Rationale: In the event of an unrecoverable vehicle pressure failure wherein an extended stay in the suit is used to maintain life, crewmembers are to have the capability to access fecal and urine collection systems. Fecal waste collection is to be performed in a manner that minimizes

escape of fecal contents into the general suit environment during microgravity operations because of the high content of possibly pathogenic bacteria contained in the stool. In addition, there is the potential of injury to crewmembers and hardware that could result from such dissemination. EVA suits are to accommodate for fecal waste collection and containment during all suited activities. Suited activities are nominally not expected to exceed 10 hours. The waste quantities reflect the altered composition of the nutrition supplied during contingency suited operations and are characteristically low in residue.]

11.1.5.6 Suit Isolation of Vomitus

[V2 11017] Suits **shall** be shown to not create any catastrophic hazards in the event of vomitus from the crewmember.

[Rationale: Space adaptation sickness (SAS) has affected crewmembers in the first 72 hours of flight. The crew is nominally suited during the first 72 hours of flight for certain dynamic phases; vomiting in the suit may occur at these times or if a contingency EVA occurs within that timeframe. On the planetary surface, a high magnitude SPE could result in exposures that produce prodromal nausea and vomiting. If vomitus enters the internal suit environment, it must be kept away from the suited crewmember's naso-pharyngeal space. Uncontrolled accumulation of vomitus may also interfere with a crewmember's vision.]

11.1.6 Suit Vision

11.1.6.1 Suited Field of Regard

[V2 11018] Suits **shall** provide a field of regard sufficient to allow the crewmember to accomplish required suited tasks.

[Rationale: To enhance work efficiency index and mission success, the visor is to have minimal interference with nominal visual acuity. The visor is to promote an adequate field of regard to perform ground, IVA, and EVA tasks and prevent tunnel vision. Suit designers need to consult with vehicle designers.]

11.1.6.2 Suit Helmet Optical Quality

[V2 11019] Suit helmets **shall** have sufficient optical qualities to allow the crewmember to accomplish required suited tasks and maintain a level of SA necessary to maintain safety.

[Rationale: To enhance work efficiency index and mission success, the visor is to have minimal interference with nominal visual acuity. The visor is to minimize haze, discoloration, and fog.]

11.1.6.3 Suit Helmet Luminance Shielding

[V2 11020] Suit helmets **shall** provide protection to suited crewmembers from viewing objects with luminance that could prevent successful completion of required suited tasks.

[Rationale: Individual tasks or crewmembers may require or desire higher or lower lighting levels than that provided for other tasks or crewmembers.]

11.1.6.4 Suit Helmet Visual Distortions

[V2 11021] Suit helmets **shall** be free from visual distortion.

[Rationale: To enhance mission success, vision through a suited crewmember's helmet is to be free of visual distortion.]

11.1.6.5 Suit Helmet Displays

[V2 11022] Suit helmet field of regard **shall** be unencumbered if helmet- or head-mounted displays are provided.

[Rationale: To enhance mission success, vision through a suited crewmember's helmet is to have minimal interference with nominal visual acuity. Inclusion of any display in the helmet is to promote an adequate field of regard to perform ground, IVA, and EVA tasks and prevent tunnel vision.]

11.1.7 Suit Information Management

[V2 11023] The system **shall** allow the crewmember to effectively input, store, receive, display, process, distribute, update, monitor and dispose of relevant information on consumable levels, suit status and alerts, and biomedical data.

[Rationale: Feedback of relevant suit atmospheric and physiologic information to the crew allows better consumable management, improves optimization of EVA task performance, and reduces risk of physiologic stress/injury. Having insight into trends in physiological parameters and life-sustaining consumables allows the IVA or EVA crew to act prospectively in preventing unsafe operating conditions or responding to off-nominal scenarios. This requirement may be met by integrated systems with the details of each system's responsibility defined in individual System Requirements Documents (SRDs) and in Information Requirements Documents (IRDs). Where feasible, it may be desirable for ground medical support to see biomedical telemetry during contingency and mission-preserving EVA, as well as during unrecoverable vehicle pressure loss, to ensure the health and safety of the crew. These data will also be monitored during nominal lunar surface operations to ensure the health and safety of the crew, although automated suit algorithms may be the primary method rather than ground medical support. Derived body core temperature and heart rhythm (real-time) are desired for microgravity operations, and derived body core temperature is desired for lunar operations. Note that crew may refer to the suited crewmember, the intravehicular crew, or ground crew. The recipients of the data must be defined by the program or project. Relevant information is determined through task analysis.]

11.1.8 Pressure Suits for Protection from Cabin Depressurization

[V2 11100] The system **shall** provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization (such as in mission dockings, operations during periods of high incidence of micrometeoroids and orbital debris (MMOD) or complex vehicle maneuvers).

[Rationale: Pressure suits for each crewmember are required to protect the crew in the event of a large cabin leak beyond the vehicle's ability to feed and maintain a habitable atmosphere for an operationally relevant period of time. The duration the vehicle/suit system must maintain habitability during exploration class missions may be orders of magnitude longer than during LEO operations, where emergency return to Earth can be measured in hours. The use of pressure suits increases the probability of crew survival by allowing crewmembers sufficient time to remedy any vehicle failure and arrive at the next closest breathable atmosphere, either on Earth or alternative safe haven.

Launch, entry, and descent operations have the increased probability of decompression events based on past spaceflight history. Docking event risk profile is dependent on vehicle size, docking vestibules, and availability of access to alternate sealable pressurized volumes. For operations within the spacesuit, the crew will be protected against ebullism, hypoxia, toxic exposure and decompression sickness. Refer to the Chapter 11 for requirements (such as required O_2 and CO_2 concentrations, DCS prevention, suit pressures, waste management, etc.) associated with the design and capabilities of a pressure suit.

Note: Alternate methods of providing equivalent protection against decompression events are evaluated for each operational scenario. Also, reference [V2 9053] Protective Equipment for applicability.]

11.2 Suited Functions

11.2.1 Ability to Work in Suits

[V2 11024] Suits **shall** provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.

[Rationale: Suited crewmembers are to be able to perform tasks required to meet mission goals and operate human-system interfaces required for use during suited operations. Suits can limit the crew mobility, dexterity, and tactility to below that of an unsuited crewmember. Wear and tear on the suit as exposed to extraterrestrial environments must also be considered. Suit pressurization can further reduce crewmember capabilities. For example, the crewmember must not have to remove gloves to operate the controls while in the LEA suit. In the event of a rapid decompression event, the crewmember will not likely have enough time to don any unsecured

equipment. Additionally, this will also need to include the ability for a suited crewmember to operate and work with any surface or rover activities.]

11.2.2 Suited Nutrition

[V2 11025] The system **shall** provide a means for crewmember nutrition in pressure suits designed for surface (e.g., Moon or Mars) EVAs of more than 4 hours in duration or any suited activities greater than 12 hours in duration.

[Rationale: Additional nutrients, including fluids, are necessary during suited operations as crewmember energy expenditure is greater during those activities. Additional kilocalories (kcal), based on metabolic energy replacement requirements from moderate to heavy EVA tasks, allow the crewmember to maintain lean body weight during the course of the mission. Lean body (especially muscular) weight maintenance is a key component of preserving crew health during missions and keeping performance at a level required to complete mission objectives. Nutritional supply during suited operations allows the crewmembers to maintain high performance levels throughout the duration of the EVA. Apollo astronauts strongly recommended the availability of a high-energy substance, either liquid or solid, for consumption during a surface EVA as mentioned in the Apollo Medical Summit. During contingency microgravity EVAs and/or for EVAs less than 4 hours in duration, this capability is not required. During long-duration suited operations such as an unplanned pressure reduction scenario, the crew is to be able to consume nutrition from an external source to maintain crew performance.]

11.2.3 Drinking Water

11.2.3.1 LEA Suited Hydration

[V2 11029] The system **shall** provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 2 L (67.6 fl oz) per 24 hours for the LEA suit.

[Rationale: Potable water is necessary during suited operations to prevent dehydration caused by perspiration and insensible water loss, as well as to improve crewmember comfort. LEA-suited hydration must be available both while suited and unpressurized as well as suited and pressurized. Having the potable water system be rechargeable from an external source is acceptable as long as the suit system has sufficient capacity to allow on-demand ready access to water at crewmember discretion without impacting work efficiency. During long-duration LEA-suited operations such as an unplanned pressure reduction scenario, the crew is to be able to consume water from an external source to prevent crew performance degradation associated with dehydration.]

11.2.3.2 EVA Suited Hydration

[V2 11030] The system **shall** provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 240 mL (8.1 fl oz) per hour for EVA suited operations.

[Rationale: Potable water is necessary during suited operations to prevent dehydration caused by perspiration and insensible water loss, as well as to improve crew comfort. Having the potable water system be rechargeable from an external source is acceptable as long as the internal suit reservoir has sufficient capacity to allow ready access to water without impacting work efficiency. Hundreds of microgravity EVAs have been performed using a 950 mL (32.1 fl oz) in-suit drink bag, but this alone does not meet the minimum recommendations for hydration during moderate activity. Factors that may affect an individual's hydration needs include body size, sweat rates, thermal environment, humidity, and metabolic rate. Given the wide range of differences between people and EVA characteristics, 240 mL (8.1 fl oz)/hour is the minimum recommendation to cover most applications. During surface EVAs, crewmembers will most likely be suited for 10 hours, including approximately 7 hours expending energy on the lunar surface. Apollo astronauts strongly recommended the availability of an appropriate quantity of water for consumption during a lunar EVA. Specifically, Apollo astronauts recommended during the Apollo Medical Summit the availability of 240 mL (8.1 fl oz) per hour of water for consumption during a lunar EVA, with water available for contingency scenarios such as a 10-km walk-back in case of surface transport vehicle failure. The intent of this requirement is for the suit system to have sufficient capacity to allow on-demand ready access to water at crew-discretion without impacting work efficiency.]

11.2.4 Suited Medication Administration

[V2 11027] The system **shall** provide a means for administration of medication to a suited, pressurized crewmember for pressurized suited exposures greater than 12 hours.

[Rationale: As a contingency, administration of medication from an external source to a suited crewmember may be required at a time in which it is not possible to doff the suit, e.g., during an unplanned pressure reduction scenario. Medication and administration method designs are to be integrated into suit design. Additionally, considerations for medications to be used while a crewmember is suited will need to be assessed for use related to [V1 3004] Medical and Survival Kits.]

11.2.5 Suited Relative Humidity

[V2 11031] For suited operations, the system **shall** limit RH to the levels in Table 11.2-1—Average Relative Humidity Exposure Limits for Suited Operations.

[Rationale: Average humidity is to be maintained above the lower limits stated to ensure that the environment is not too dry for the nominal functioning of mucous membranes. During low humidity exposures, additional water is to be provided to the crew to prevent dehydration.

Humidity is to be maintained below the upper limits for crew comfort to allow for effective evaporation and to limit the formation of condensation. Excess moisture in the glove can contribute to trauma at the fingertips.]

Table 11.2-1—Average Relative Humidity Exposure Limits for Suited Operations

Average RH	Time Allowed
RH ≤ 5%	1 hr
5% < RH ≤ 15%	2 hr
15% < RH ≤ 25%	8 hr
25% < RH ≤ 75% (nominal range[1])	Indefinite[2]

1. Nominal humidity range is included for completeness.
2. Assumes temperature is within nominal range in accordance with requirement [V2 6012] Crew Health Environmental Limits in this NASA Technical Standard.

11.2.6 LEA Suited Decompression Sickness Prevention Capability

[V2 11032] LEA spacesuits **shall** be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

[Rationale: LEA spacesuits are worn inside spacecrafts to protect crewmembers in the event of contingencies such as contamination or depressurization of the spacecraft cabin. For example, in Soyuz 11, a rapid depressurization due to a faulty valve occurred at an altitude of about 104 miles, ledding to the death of all three (unsuited) crewmembers within two minutes. Protection against serious life-threatening (Type II) DCS in the event of an unplanned rapid cabin depressurization depends on providing adequate suit pressure to crewmembers because there is no opportunity for oxygen prebreathe or immediate post event treatment. Based on best available data and computational models, LEA spacesuit pressure of 40 kPa (5.8 psia) will limit the probability of Type II DCS occurrence to less than 15% for a rapid depressurization when saturated at a cabin pressure of 14.7 psia. If cabin pressure is nominally less than 14.7 psia, as expected during Exploration missions, the resulting minimum suit pressure could be less than 5.8 psia.]

11.3 Suited Atmosphere

11.3.1 Suited Thermal Control

[V2 11033] The suit **shall** allow the suited crewmembers and remote operators to adjust the suit thermal control system.

[Rationale: The ability to control suited atmospheric conditions is important for crew health and comfort, and for mission tasks, to ensure efficient and effective performance. Temperature can be adjusted in a number of ways depending on the suit and vehicle system design (e.g., changing water flow, inlet temperature.]

11.3.2 Suited Atmospheric Data Recording

[V2 11034] Systems **shall** automatically record suit pressure, ppO_2, and $ppCO_2$.

[Rationale: Access to atmospheric data is needed for suit systems, as each of these parameters is critical to crew health and comfort. Additionally, the ability to view past recorded data helps to prevent suited environmental conditions that could harm the crew or suit system and can aid in the effort to troubleshoot problems. ppO_2 can be directly measured or calculated indirectly and recorded. Recording of thermal comfort variables may be useful.]

11.3.3 Suited Atmospheric Data Displaying

[V2 11035] Suits **shall** display suit pressure, ppO_2, and $ppCO_2$ data to the suited crewmember.

[Rationale: These atmospheric parameters are critical to human health and comfort, and access to this atmospheric data needs to be provided to the crewmember. The crewmember needs to view the environmental status in real time to help prevent environmental conditions that could harm them or the suit system. The implementation of the display is addressed by various requirements in section 10 of this NASA Technical Standard.]

11.3.4 Suited Atmospheric Monitoring and Alerting

[V2 11036] Suits **shall** monitor suit pressure, ppO_2, and $ppCO_2$ and alert the crewmember when they are outside safe limits.

[Rationale: Systems are to be capable of monitoring the atmosphere to identify when parameters are outside set limits so that the system can alert the crew and the crew can take appropriate actions to maintain health and safety. See section 10.5.1, Audio Systems, in this NASA Technical Standard for additional information. Note that crew may refer to the suited crewmember, the intravehicular crew, or ground crew. The recipients of the data are defined by the program or project. Monitoring and alerting of thermal comfort variables may be useful.]

11.3.5 Nominal Spacesuit Carbon Dioxide Levels

[V2 11039] The spacesuit **shall** limit the inspired CO_2 partial pressure (P_ICO_2) in accordance with Table 11.3-1—Spacesuit Inspired Partial Pressure of CO_2 (P_ICO_2) Limits.

[Rationale: Spacesuit design (flow rate, helmet shape, etc.) and crewmember metabolic rates (average and transient) affect the extent to which CO_2 accumulates inside a spacesuit and is inspired by crewmembers. Inspired CO_2 partial pressure levels in Table 11.3-1 are based on review of scientific literature combined with past EVA experience, prescribed standardized human-in-the-loop testing, suit inlet CO_2 of <2 mmHg, and suit ventilation utilized in heritage designs. Verification methods would utilize the standardized testing method as published in ICES-2018-15, Bekdash, et al., July 2018.

Note: Off-nominal CO_2 values are not included within this NASA Technical Standard due to the unique circumstances of each mission (expected human performance, duration of exposure, access to medical care, etc.) and would be derived as a lower-level program/project requirement.]

Table 11.3-1—Spacesuit Inspired Partial Pressure of CO_2 (P_ICO_2) Limits †

P_ICO_2 (mmHg)	Allowable Cumulative Duration (hours per day)
$P_ICO_2 > 15.0$	Do Not Exceed
$12.5 < P_ICO_2 \leq 15.0$	≤ 0.5
$10.0 < P_ICO_2 \leq 12.5$	≤ 1.0
$7.0 < P_ICO_2 \leq 10.0$	≤ 2.5
$4.0 < P_ICO_2 \leq 7.0$	≤ 7.0
$P_ICO_2 \leq 4.0$	indefinite

The requirements in Table 11.3-1 are to be met in the presence of the expected average and transient metabolic rates for the full suited duration, including prebreathe, checkout, EVA, and repressurization time. Total duration in the suit is not to exceed 14 hours.

† The values in Table 11.3-1 are based on Shuttle and ISS EVA experience, representing a frequency of up to 4 EVAs over a 14-day mission or up to 5 EVAs during a 6-month mission. If additional frequency of EVAs beyond the existing experience base is required, monitoring of crewmembers for hypercapnic signs and symptoms will be necessary until a sufficient experience base is generated.

11.3.6 Contingency Spacesuit Carbon Dioxide Levels for Partial Gravity Scenarios

[V2 11040] The spacesuit inspired CO_2 partial pressure (P_iCO_2) shall not exceed 20 mmHg during contingency scenarios up to a duration of 1-hour.

[Rationale: Standard is based on review of scientific literature combined with data from ground-based testing in 1-G. The ground testing performed included levels up to 30 mmHg in a simulated 1 hour walk back test, with physiological, subjective, and cognitive measures. All of the ground-based subjects finished the tests including the 30 mmHg test with minimal physiological, subjective, and cognitive effects. The testing was performed in 1-G and with the subjects starting at ambient CO_2 levels (~ 0.4 mmHg) which is lower than the 3 mmHg nominal spaceflight vehicle standard and nominal spacesuit levels of 3-15 mmHg (see [V2 11039]). See Keller et. al, 2025 for additional information. Since the ground testing scenario is not identical to flight conditions (partial gravity and baseline vehicle CO_2 of 3 mmHg and suit CO_2 levels between 3-15 mmHg) a conservative factor has been applied to establish the limit of 20 mmHg. Note: This standard limit is to be used only during contingency scenarios where crew life is in jeopardy due to hardware failure and/or adverse operational conditions. Durations beyond 1 hour may impede the crew's ability to function both physically and cognitively.]

11.4 Suited Metabolic Rate

11.4.1 EVA Suited Metabolic Rate Measurement

[V2 11037] The system **shall** measure or calculate metabolic rates of suited EVA crewmembers.

[Rationale: Real-time monitoring during EVA is a current medical requirement and provides awareness of exertion level, including whether or not exertion levels are above or below normal for a particular crewmember and task.]

11.4.2 EVA Suited Metabolic Data Display

[V2 11038] The system **shall** display metabolic data of suited EVA crewmembers to the crew.

[Rationale: Metabolic data are important indicators of human health and performance, and access to these data needs to be provided to the crew. The crew needs to view the metabolic information in real time to provide awareness and potential adjustment of exertion level, including whether or not exertion levels are above or below normal for a particular crewmember and task. Note that crew may refer to the suited crewmember, the intravehicular crew, or ground crew. The recipients of the data are defined by the program or project.]

11.5 Incapacitated Crew Rescue (ICR)

[V2 11101] Resources **shall** be provided to rescue an incapacitated suited crewmember(s).

[Rationale: Incapacitation of a suited crewmember can occur in microgravity or on planetary surfaces. An incapacitation event could render the affected crewmember partially or fully reliant on the rescuer crewmember either temporarily or continually during the ICR. Resources needed during an ICR include appropriate hardware aids (restraints, translational aids, lifting handles, hoisting devices, etc.), consumables, and operational planning for both the incapacitated crewmember and rescue crewmember for all ICR phases. ICR phases encompass the initial occurrence of the event through medical stabilization of the incapacitated crewmember inside the vehicle (including suit doffing).]

12. GROUND ASSEMBLY DESIGN AND EMERGENCY EGRESS OPERATIONS

This section focuses on the design of spaceflight systems, hardware, and equipment that are accessed, used, or interfaced in some way by personnel other than the spaceflight crews (e.g., ground support personnel) during preflight ground processing, launch, landing, recovery, contingency, and ground emergency egress operations.

12.1 Ground Assembly Design

This section focuses on the design of spaceflight systems, hardware, and equipment that are accessed, used, or interfaced in some way by personnel other than just the spaceflight crews (e.g., ground support personnel). Spaceflight systems include those systems that support crew launch, orbit, transit, surface ops, return, and recovery. Ground support personnel perform numerous tasks utilizing spaceflight systems, hardware, and equipment at times other than during spaceflight such as during ground operations before launches and after landings. Incapable, incomplete, or improper performance of tasks and/or improper use of hardware and equipment by the ground support personnel could lead to loss of mission or loss of crew of the spaceflight crew.

The requirements in this section ensure that the capabilities and needs of the ground processing crew are considered during the design and development of the flight system along with ensuring that the flight system is not compromised during the assembly, test, and operational phases.

The requirements listed in section 12.1 of this NASA Technical Standard apply only to the design and development of flight systems interfaced by ground support personnel at integration, launch, landing, recovery, and deservicing sites. These requirements are optional for designs at manufacturing and development sites.

This section is applicable for the following: when NASA is performing the ground processing for vehicles built by non-NASA vendors or when one vendor builds the vehicle and a second vendor is responsible for the assembly, integration, and maintenance. If one vendor is responsible for the design, assembly, and maintenance, then this section does not apply.

12.1.1 System Assumptions

[V2 12003] Each human spaceflight program **shall** document the system support design and environment:

a. Work environment (e.g., lighting, heating, atmosphere, gravity)

b. Tools and support equipment

c. Ground support personnel characteristics (e.g., size, training, experience, number, physical and cognitive capabilities, skills, ergonomics)

d. Ground support personnel tasks (e.g., environment, complexity, scheduling)

[Rationale: A separate support system (i.e., facilities, equipment, personnel, procedures) is required to support the spaceflight system. The two systems must work together so that the spaceflight system can achieve its performance goals. The spaceflight system developer may not be in control of the support system; but to properly design the spaceflight system, the developer must have a clear understanding of the support system, including its functions and users.]

12.1.2 Ground Support Personnel Accommodation

12.1.2.1 Anthropometry, Biomechanics, Range of Motion, and Strength

[V2 12004] Each program **shall** identify an anthropometry, biomechanics, range of motion, and strength data set for the ground support population to be accommodated in support of all requirements in Appendix E, Physical Characteristics and Capabilities.

[Rationale: Ground support personnel anthropometry, reach, biomechanics, range of motion, and strength need to be defined for the program in a data set. Ground support personnel data sets may represent different populations than spaceflight crew. Systems need to accommodate the physical capabilities and limitations of ground support personnel to allow for required servicing, maintenance, assembly, testing, or operational use by ground support personnel (e.g., rescue, flight test, special docking). Systems architecture and vehicle layout and tasks must not force ground support personnel to move, twist, or stretch into awkward positions. Tasks that require awkward positioning can increase the likelihood of errors or injury.]

12.1.2.2 Protective Equipment

[V2 12005] The system **shall** accommodate ground personnel protective equipment and attire.

[Rationale: The design must accommodate for ground personnel functions constrained or increased by protective equipment or combinations of such (e.g., pressurized or unpressurized suits, breathing hoses or air packs, gloves, fall protection harnesses, masks, hats or helmets, sensors, cords). Protective equipment often limits human capabilities (e.g., visual envelope, range of motion, reach envelope, audio, communication, grasp) and often increases personnel work volumes or quantity of personnel anticipated (e.g., pressurized suited tasks often require a minimum of two personnel and air packs or hoses). Design factors for audio, communication, displays, and control systems must accommodate for face, ear, and/or hand protection (e.g., larger knobs, increased volume, larger tactile surfaces, resistive touchscreens). Integrated task analysis must be performed to identify designs or functions that may be affected by protective equipment or attire. Physical characteristics of protective equipment need to be provided to designers so the protective equipment can be accommodated in system design.]

12.1.2.3 Volume Accommodation

[V2 12006] The system **shall** provide the volume necessary for the ground support personnel to perform all ground processing tasks using the required tools and equipment.

[Rationale: The physical work envelopes must accommodate full or partial access for the expected number of ground support personnel, equipment required to perform the task, and any associated protective equipment. The volume must also accommodate body, work, reach, visual, tool, and protective equipment envelopes to accomplish the task. The physical work envelopes of doors, hatches, and entryways must consider further volumetric restrictions imposed by ground processing, including door/hatch masses and hinges, if captive, actuators, or other entry mechanisms along with air ducts, cords, sensors, protective covers, safety equipment, portable lighting, and potential mechanical assist devices (e.g., personnel and equipment entry platforms, lift devices). For safe passage, timeliness, and to prevent collateral damage, hatches and ingress/egress openings must be large enough for the ground support personnel to pass safely and efficiently in situations involving suited personnel, transporting equipment or hardware through the opening, emergency or contingency operations, or incapacitated personnel rescue.]

12.1.2.4 Ground Processing – Induced Forces

[V2 12007] Systems, hardware, and equipment **shall** be protected from or be capable of withstanding forces imposed by the ground support personnel or ground support equipment (GSE), in a 1-g environment.

[Rationale: Either by vehicle design (preferred) or through other means (e.g., labels, placards, covers, training, walking platforms, procedures), the spaceflight system needs to be protected from the forces imposed by ground support personnel (and their associated equipment) while performing vehicle tasks. Furthermore, any accessible items that could be inappropriately used such as handles, steps, handrails, or mobility aids are to be either designed to withstand the forces imposed by the ground support personnel or be clearly labeled as a keep-out zone. Historical experience with Shuttle and ISS has shown that it is important to make it clear which parts of a vehicle may not be used as handles, steps, or handrails so that ground support and spaceflight crews do not inadvertently damage delicate portions of the vehicle. Priority is given to areas where ground support and spaceflight crews will traverse and /or work most frequently and those areas with the most severe potential hazard consequences.]

12.1.2.5 Systems Accessibility

[V2 12008] System components, hardware, and/or equipment that requires ground support personnel inspection or interaction **shall** be accessible.

[Rationale: Ground support personnel must be able to access system components, hardware, or equipment that requires inspection or interaction. Consideration needs to be given for type of access and inspection (e.g., physical and visual) needed for each component, hardware, and

equipment during vehicle design. Proximity and envelope required for the access and inspection is defined by the function.]

12.1.2.6 Tool Clearance

[V2 12009] The system **shall** provide tool clearances for tool installation and actuation for all tool interfaces during ground processing.

[Rationale: The required tool clearance for fit and actuation is to be determined and applied to the design of hardware. Consideration needs to be given to type of tool, the user's hand action, the tool's motion envelope and forces needed, the user population hand anthropometric data, adjacent equipment, the inclusion and use of appropriate shields/guards/gloves, and the need for tool tethering when determining the minimum clearance dimensions.]

12.1.3 Hardware and Software Design to Support Ground Operations

12.1.3.1 Flight Hardware Differentiation

[V2 12010] Flight system components that have the same or similar form, but different functions **shall not** be physically interchangeable.

[Rationale: Components requiring installation (including, but not limited to, Line Replacement Units (LRUs)) that are not interchangeable functionally will not be interchangeable physically. This requirement addresses installation of a component in the wrong location. While some installable units may be used for the same function in multiple instances (e.g., redundant strings), many may be physically similar but functionally distinct. In such cases, installation in the wrong location could result in damage to the hardware or to the system into which it is inserted. This requirement is intended to preclude such installation in the wrong location. Physical designs may include incompatible bolt patterns, pin/hole alignment, and/or baseplate differences that do not allow incorrect and/or inadvertent location installation. In addition to differentiation, labeling to show distinctions is also applied.]

12.1.3.2 Hardware Protection

[V2 12011] The system **shall** provide a means of protecting flight hardware and equipment from damage during ground processing.

[Rationale: Equipment that can reasonably sustain damage during ground processing must have a means of being protected during ground operations (e.g., window covers, wire covers, propulsion line covers). Note that removable Ground Support Equipment can be used to accomplish this goal.]

12.1.3.3 Mobility Aids

[V2 12012] The system **shall** provide mobility aids to support expected ground support personnel tasks.

[Rationale: Mobility aids such as handholds allow ground support personnel to safely and efficiently move from one location to another, preventing inadvertent damage to equipment. Required tasks will need to be determined by task analysis, which will include the identification of mobility aids.]

12.1.3.4 Equipment Handling Design

[V2 12013] All items designed to be carried, supported, or removed and replaced **shall** have a means for grasping, handling, and carrying.

[Rationale: This requirement is intended to avoid damage to flight hardware and to prevent injury to ground support personnel. Items that are unable to be reasonably moved may incur injury to ground support personnel or damage to the flight systems if handled inappropriately. Flight items that must be moved may be damaged if handled inappropriately. Damage to flight hardware and injury to the ground support personnel can result from poor grips on a non-handle protrusion or from protrusions that do not hold the weight of the hardware. Non-handle protrusions can break and lead to dropping flight hardware. Handles or handholds need to be designed to support the weight of the hardware, any lifting mechanisms, accommodate bare or gloved hands where appropriate, be non-slip, and/or be clearly labeled.]

12.1.3.5 Inadvertent Operation Prevention

[V2 12014] The system **shall** be designed to prevent inadvertent operation of controls during ground processing.

[Rationale: The system needs to be designed to preclude inadvertent operation. For example, accidental activation by contact can be prevented by the use of guards, covers, and physical separation from other controls. Accidental activation of commands can be prevented with an "arm-fire" mechanism. Two-step commanding allows for ground support personnel confirmation before completing critical, hazardous, or destructive commands. Controls need to be spaced to prevent inadvertent actuation of adjacent switches. For example, hard plastic, molded covers may be placed over contact-sensitive items, covers placed over adjacent switches, or metal foot and handholds may be added to assure only applicable steps are executed.]

12.1.3.6 Incorrect Installation Prevention

[V2 12015] System hardware and equipment **shall** be designed to prevent incorrect mounting or installation.

[Rationale: This requirement is intended to assure that fasteners are inserted in the correct holes, brackets are attached in the correct location, connectors are installed in the correct position, etc. Improperly mounting equipment during ground processing will result in unsafe conditions for spaceflight crews and increase the risk of loss of crew or loss of mission events through damage to hardware or changes in configuration during launch and ascent. Physical features to prevent incorrect mounting or installation largely prevent these situations. Examples of physical features include supports, guides, size or shape differences, fastener locations, and alignment pins. Physical features are the first line of defense for preventing such errors. In addition to physical features, labeling or marking mitigates human error. Visual indication might include any marking on or adjacent to the hardware/equipment interface, labels, or color coding that provides information about mounting. Unique labeling of hardware/equipment provides an indication that the item to be mounted and the mounting location match. Labels provide contextual information to help assure that the ground support personnel do not attempt to install a hardware item incorrectly; such an attempt could damage the hardware or the interfaces on the vehicle.]

12.1.3.7 Pre-Defined Tool Set

[V2 12016] The system **shall** be designed to be assembled, prepared for launch, maintained, and reconfigured using a pre-defined set of standard tools and lesser set of any pre-established set of specialized tools.

[Rationale: Establishing a minimal set of tools for pre- and post-mission processing of flight hardware requires integration across spaceflight systems, hardware, and equipment designs. The goal is to have an integrated set of tools (across systems or programs) that can be used for all ground processing tasks, using common tools wherever possible. Defined toolsets would reduce the number and types of tools and subsequently reduce the number and types of fasteners. Minimizing the variations and quantity within the tool set reduces training time, processing time, potential damage to hardware and injury to personnel, and decreases the chance of using the wrong tool for the task. System designs and tool determinations must accommodate tool reach, grasps, and volumes of ground personnel populations, tool motions, and any concurrent flight system component volume needed around the tool use. For example, designs should account for tools being used by one person while adjacent personnel assist in securing the weight or positioning of a removable or tested component. Tool grasps, weights, tethering, and clearance may also be affected by varying postures needed for access or visibility. Integrated task analyses are performed to support use of common tools or determine where specialized tools may need to be pre-defined.]

12.1.3.8 Captive Fasteners

[V2 12017] Fasteners on installable units **shall** be captive.

[Rationale: A captive fastener is one that is automatically retained in a work piece when it is not performing its load-bearing job. Captive fasteners for maintenance, assembly, integration, and processing tasks, therefore, do not require ground support personnel to restrain and store them

during task performance, and can more easily be installed with one hand, reducing task times and reducing the chance of fastener loss. Dropped fasteners could become Foreign Object Debris (FOD), which pose a risk during the mission. They can cause injury, impact launch schedule, and damage equipment.]

12.1.3.9 Ground Processing Without Damage

[V2 12018] The system **shall** be designed for assembly, testing and checkout, troubleshooting, and maintenance that prevents damage to other components.

[Rationale: Damage to certified flight components will cause costly recertification and may impact the launch. This requirement is intended to limit such damage and recertification by maintaining a flight configuration for all systems that are not part of the maintenance activity and providing mitigation strategies when possible. To define the necessary accommodations for maintenance without damage, an integrated task analysis must be performed for each maintenance activity. Methods that have been successfully used to preclude damaging other components during maintenance include the following: (1) routing cables to prevent mechanical damage, pinching by doors, or twisting; (2) protecting against inadvertent actuation; and (3) implementing provisions for components that are susceptible to abuse or those frequently used.]

12.1.3.10 Replaceable Items

[V2 12019] The system **shall** locate maintenance items so that a planned ground processing or corrective or preventive maintenance task does not require the deintegration or demating of other systems or components.

[Rationale: Deintegration of certified flight components will cause costly recertification if disturbed. This requirement is intended to limit damage and recertification by maintaining a flight configuration of all systems and providing mitigation strategies when possible. Corrective maintenance is limited to LRUs, whereas preventive maintenance is a planned maintenance activity (e.g., battery replacement). To define the necessary accommodations for maintenance without damage, an integrated task analysis must be performed for each maintenance activity.]

12.1.3.11 Visual Access for Ground Processing

[V2 12020] The system **shall** provide direct line-of-sight visual access to all flight system components requiring inspections or other human-system interactions, except self-mating connectors, on which ground processing is performed by ground personnel.

[Rationale: Direct line-of-site visual access reduces the likelihood of human error that can occur when blind (by feel) operations or operations requiring the use of specialized tools (e.g., mirrors or bore scopes) are performed. The addition of obstructions from the hands, tools, equipment, PPE (e.g., gloves, protective suits), corrective lenses, and the components or cabling needs to be considered during the line-of-sight operation. Reliance on just the "feel" of the hardware introduces human error variances. A self-mating connector is a connector that, when

two pieces of hardware slide into place, they automatically self-mate. See requirement [V2 12014] Inadvertent Operation Prevention.]

12.1.3.12 Lighting

[V2 12021] The flight system in combination with ground support equipment **shall** provide lighting to perform ground processing tasks in the vehicle.

[Rationale: Lighting is required to ensure that the ground support personnel can adequately view the hardware/equipment associated with the task, and it is generally accomplished through GSE but may include flight lighting. Additionally, this may require an integrated solution, utilizing the flight vehicle and ground equipment providers. Lighting or illumination types, levels, controls, selection, and design factors are to accommodate general assembly or bench work tasks down to extra fine precision while accounting for lux or lumen levels, shadow prevention, indirect and direct glare mitigations, color temperature, brightness adjustability, dark adaptation, color rendering, and lighting color techniques (e.g., red flood, low-color temperature, bright markings [foot-lamberts]). Variations in operating conditions such as natural sunlight, artificial lighting, or filtering must also be considered.]

12.1.3.13 Supplemental Systems

[V2 12022] The system **shall** be designed to support any supplemental systems that are required to assist ground support personnel when an assigned task cannot reliably, safely, or effectively be performed by ground support personnel alone.

[Rationale: Tasks that cannot be reliably, safely, or efficiently performed by the ground support personnel are to be identified. In those cases, supplemental systems (such as GSE) will need to be accommodated in design. This may include providing attach points for GSE, rails, tracking or removal guides, and/or accommodation of ground support lighting.]

12.1.3.14 Operational Consistency

[V2 12023] The system **shall** be designed for consistent operation across ground processing tasks.

[Rationale: The intent of this requirement is to ensure commonality and consistency across flight systems. This will facilitate learning and minimize interface-induced ground support personnel error. Examples include consistent use of control direction ("on" is always "up"), "closed" direction is always the same (right), consistent use of a release mechanism, terminology, markings, color coding, etc.]

12.1.3.15 Restraints and Platforms

[V2 12024] The system **shall** accommodate restraint and platform placement that ensures the reach and work envelope of the suited or unsuited ground support personnel for the required tasks.

[Rationale: Restraints and platforms are intended to keep personnel from falling (or related hazards), allow for hardware access, and protect the hardware from inadvertent ground support personnel collision. A task analysis will identify locations where restraints and platforms are needed. A worksite analysis will inform the placement and design the restraints and platforms needed.]

12.1.3.16 System Feedback

[V2 12025] The system **shall** provide feedback to the operator indicating successful task completion.

[Rationale: Feedback can include visual indication, audible click, handle position, bolt height, alert, etc. Feedback at task completion is important to prevent continual inputs into the system, which may lead to damage to the system. For example, when filling a tank, feedback that the tank is full is important to prevent overfilling, which may result in human injury or hardware/equipment damage. If system feedback is not possible, another means of feedback is necessary (i.e., GSE). For example, if the system does not provide indication of a full tank, the equipment used to fill the tank can provide the feedback.]

12.1.3.17 Stowage Access

[V2 12026] The system **shall** provide access for ground support personnel to spacecraft stowage volumes that require late loading and early unloading of items.

[Rationale: Ground personnel are responsible for any "late loading" of items such as fresh food, pharmaceuticals, and experiment items with short lifetimes that need to be placed onboard the spacecraft within 24 hours of launch. Similarly, "early access" items need to be retrieved off the spacecraft within a short time after landing. Regular unloading requires waiting until the spacecraft returns to the processing facility, which could be weeks later. The intent of this requirement is to allow the ground support personnel to perform these access operations safely without disruption to the spaceflight crew or spacecraft.]

12.1.3.18 Flight Software Systems

[V2 12027] The system **shall** allow the ground support personnel safe operation of flight software systems for ground processing.

[Rationale: Ground support personnel may be required to access flight software systems during ground operations tasks. Therefore, it is critical for flight software systems to have a mode or configuration for safe operation by ground support personnel.]

12.1.4 Safety

12.1.4.1 Sharp Edge and Burr Injury Prevention

[V2 12028] The system **shall** protect ground support personnel from injury resulting from sharp edges and burrs.

[Rationale: Protection of ground support personnel from injury controls ground operations costs by assuring that bodily fluids, such as blood, do not contaminate flight systems, degrading flight safety. In those areas that the ground support personnel would access for ground processing and maintenance, the design must protect them from burrs, sharp edges, and sharp corners. Support personnel may have an additional risk that system hardware may be in a more exposed configuration during maintenance or installation/removal operations. The intent of this requirement is for a design solution, not an operational solution, since the latter results in expensive recurring costs. The requirement may be met by rounding of edges and corners, sanding burrs, or by designing flight structure that hides sharp edges and corners and burrs from ground personnel during planned operations. It cannot be met by design of remove-before-flight protective structure.]

12.1.4.2 Pinch Point Prevention

[V2 12029] The system **shall** be designed to protect ground personnel from injury due to pinch points.

[Rationale: A pinch point can cause injury to ground personnel or damage to hardware if not protected. Pinch points may exist for the nominal function of equipment (i.e., equipment panels), but need to be covered or protected during ground operations. Injury may be avoided by locating pinch points out of the reach of the ground personnel or providing guards to eliminate the potential to cause injury.]

12.1.4.3 Hazard Controls

[V2 12030] The system **shall** be designed to prevent unnecessary exposure of ground support personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy.

[Rationale: Ground support personnel must not be exposed to hazards unnecessarily. Spill hazards can be avoided by capturing the spill or by adding extensions to the flight vehicle to relocate the hose to flight connection away from the vehicle. Electrical exposure can be avoided by shielding, interlocks, and de-energizing electrical stored energy. Interlocks must not be the

sole mean of de-energizing electrical circuits of equipment and are not substitutes for lockout and tag-out procedures and practice.]

12.1.4.4 System Safing for Ground Operations

[V2 12031] The system **shall** alert and allow ground personnel to safe the system before performing any ground operation.

[Rationale: Elements or systems must provide methods for system safing during ground assembly and maintenance activities to protect the system, hardware, and equipment from damage or personnel from injury. To ensure all areas in which a method is to be in place for system safing, an integrated task analysis must be performed. The system must alert ground personnel of unsafe conditions. To safe or unsafe a system, a combination of mechanical actuation (physical lockout) with corresponding indicators (tagout means) allows ground personnel to engage or disengage the system while informing personnel of safe or unsafe conditions (e.g., flashing or steady lights of various colors, distinct audio alarms, positive locking engagements, other status indicators using multiple modalities). Safing or unsafing mechanisms and controls must be accessible to ground personnel for safe and timely execution. Methods that have been successfully used as controls for system safing include physical protection, interlocks, software disabling or multiple key combinations, cut-out switches, warning placards, and guards.]

12.1.4.5 Contamination Controls

[V2 12032] The system **shall** have controls in place to prevent the introduction of contaminants to the flight vehicle.

[Rationale: Elements or systems cannot release hazardous or non-hazardous materials into the spaceflight system during maintenance activities. Controls must be designed to prevent contamination.]

12.1.4.6 Containment of Fluids and Gases

[V2 12033] The system **shall** provide for containment and disposal of fluids and gases inadvertently released into the flight system.

[Rationale: This can be accomplished by isolating, draining, or venting pressurized fluids. System developers are to identify the containment points and create isolation capabilities. The control valves are to be located near those service points to avoid control errors.]

12.1.4.7 Safe Weight Limit

[V2 12034] Hardware and equipment installed or removed by ground support personnel without ground support equipment **shall** be less than a safe weight limit.

[Rationale: Handling of hardware and equipment that is too heavy can result in injury or damage to the equipment (e.g., dropped hardware). NIOSH has published a lifting equation, designed to determine a recommended weight limit for safely lifting loads. It accounts for factors that would affect a person's ability to lift, including the position of the load relative to the body, the distance lifted, the frequency of lifts, and the coupling (gripping) method. These various factors need to be accounted for while determining safe weight limits for the ground support personnel during assembly, processing, and maintenance tasks. Other factors such as obstructions, surrounding environment, and the carefulness needed in placing an object is also considered in design.]

12.1.4.8 Safe Flight System Component Arrangement

[V2 12035] Flight system components **shall** be arranged, or located to prevent hazards, interference, or errors during concurrent ground processing tasks.

[Rationale: Hardware, personnel, software, and/or automation could interact in such a way during concurrent tasks as to create undesired outcomes. For example, crossing cables during installation may lead to inadvertent forces on those cables which may cause problems in-flight. The system and components must provide a means of damage detection by inspection or test and a means to recover. Consequences of errors on safety or system performance must be made clear. Placing items in view on system mold lines, rather than stacked or hidden, can provide visual indicators of damage or interferences. Obtaining a test failure must indicate the isolated area of the fault, and the system provides physical and visual means to the affected area. For pneumatic systems, clear sight glasses have been incorporated showing mechanical indicators to clearly identify performance flow or inoperability. In software or instrumentation, system status windows with conditional indicators for online, offline, optimal, or off nominal, can provide means of detecting the failure or damage in time to recover before flight.]

12.1.5 Connectors

12.1.5.1 Connector Design and Spacing

[V2 12036] Connectors **shall** be designed and spaced to allow for accurate, damage-free mating and demating by ground support personnel.

[Rationale: Connectors need to be grasped firmly for connecting and disconnecting. The clothing, gloves, equipment, and PPE worn by the ground support personnel during the task must be considered in design.]

12.1.5.2 Connector Incorrect Mating Prevention

[V2 12037] Connectors **shall** have physical features to preclude incorrect mating and mismating. This can be accomplished by differing connector shell sizes, differing connector keyway arrangements, and having different contact arrangements (these are listed in order of most preferred to least preferred).

[Rationale: Connector similarity could lead to inadvertent mismating, which is the mating of a male plug to the wrong female jack. Mismating can damage pins or mechanisms, or even (once powered or filled with fluids) lead to personal injury or equipment damage. Incomplete electrical connector mating can result in short circuits or open circuits. Incomplete fluid connector mates, especially in pressurized systems, can result in unexpected and possibly hazardous fluid release. Physical features such as color coding, different size connectors, connector keying, and tactile feedback can help ensure proper installation. Connector savers can be used to reduce the probability of extensive rework caused by high repetition of mating/demating or the possibility of mismating. Labels can help to identify which connector plug is intended to be mated with which jack, as well as proper orientation for mating.]

12.1.6 Labels

These requirements ensure that the design and placement of labels allow users to locate and identify controls and human interfaces, to interpret and follow procedures, or to avoid hazards. Labels may include permanent labels, placards, etchings, engravings, part markings, decals, ink-stamped labels, engraved labels, or silk-screened labels.

12.1.6.1 Label Provisions

[V2 12038] Labels and placards **shall** be provided for the ground support personnel to identify items, interpret and follow procedures, and avoid hazards.

[Rationale: Ground support personnel interface items must have identifiers (labels) to aid in assembly, maintenance, test, and checkout operations. Labels for ground support personnel interfaces help prevent ground processing mishaps, process escapes, and human errors. Labels need to be positioned so it is intuitive which item is being identified. Labels reduce memory load and improve accuracy of tasks. This includes, but is not limited to, identification of emergency equipment and procedures, safe weight limits, and hazards identification.]

12.1.6.2 Label Standardization

[V2 12039] Labels and placards **shall** be consistent and standardized throughout the system.

[Rationale: Systems, hardware, and equipment that are intended to be used by ground support personnel and the spaceflight crew need to employ standardized nomenclature, label formats, coding, language, measurement units, and icons in concordance with the space vehicle system.]

12.1.6.3 Label Content

[V2 12040] The content of labels and placards **shall** be of sufficient size, color contrast, and character height and style to support readability.

[Rationale: Labels and placards need to be readable at the intended viewing distance. Designers need to consider the distances at which the labels and placards are expected to be viewed, any worn PPE, and the lighting conditions in which the labels and placards will be viewed.]

12.1.6.4 Readable Label Positioning

[V2 12041] Labels and placards **shall** be located such that they are readable by the operator, considering ambient lighting conditions, orientation in the integrated configuration, and position of the operator relative to the label.

[Rationale: Labels and placards need to be readable in the normal operating position. Designers need to consider the lighting conditions for the operation of the hardware and make sure the labels are readable, given the task demands.]

12.1.6.5 Non-Obstructive Labels

[V2 12042] Labels, placards, or part markings used for ground processing **shall not** visually or operationally interfere with spaceflight crew interface labeling.

[Rationale: Spaceflight crew interface flight labeling must take precedence over ground labeling to ensure safe flight operations. Interference with the flight labeling by ground labeling can cause confusion for the spaceflight crew. When and where possible, the ground labeling must not be visible to the crew in-flight.]

12.2 Emergency Egress Operations

The capability for ground support personnel emergency egress and access to medical care during ground processing, preflight and postflight is critical to ensure the safety and health of ground and spaceflight crews. Note these requirements augment the requirement in NPR 8705.2, section 3.6.1.1, that requires the space system to provide the capability for unassisted crew emergency egress to a safe haven during Earth prelaunch activities.

12.2.1 Emergency Egress at the Launch Site

[V2 12043] The system **shall** be designed such that the spaceflight crew and ground support personnel can egress within the time required to preserve the health and safety of all spaceflight crew and ground support personnel in the event of an emergency.

[Rationale: Spaceflight crew egress may require the assistance from ground support personnel, and ground support personnel may need to egress due to emergencies during processing. Ground support personnel wearing protective clothing need to be accommodated, in addition to the spaceflight crewmember wearing an ascent/entry suit during emergency egress scenarios. Ground support protective clothing may include a bulky backpack and air tank. Egress scenarios need to be evaluated to adequately configure the egress paths in the design.]

12.2.2 Emergency Egress to Medical Care

[V2 12044] The system **shall** be designed to ensure spaceflight crew and ground support personnel can egress to a location providing advanced pre-hospital life support.

[Rationale: Egress systems primarily relocate personnel to a safe location. Upon an emergency egress, it is possible that medical care will be needed. An egress system that delivers personnel to a location that provides advanced pre-hospital life support is important to prevent delayed medical treatment.]

12.2.3 Nominal Timely Egress

[V2 12045] Following a post mission nominal landing, launch scrub, or abort scenario, crew egress from the system **shall** be expedited to ensure crew health.

[Rationale: Environmental, safety, and health considerations may necessitate expedited egress. For the well-being of all crewmembers, it is necessary to expedite egress. For example, it is possible that one or more crewmembers may experience health issues following a re-adaptation to Earth's gravity. In addition, following a launch scrub/mission abort, vehicle troubleshooting may be required quickly after crew egress.]

12.2.4 Emergency Egress Acceleration Limits

[V2 12046] For ground emergency egress systems (EES), the system **shall** limit the magnitude and direction of crew exposure to accelerations according to Table 12.1-1—EES Acceleration Limits – Sustained, and Table 12.1-2—EES Acceleration Limits – Jerk.

[Rationale: Emergency egress systems must provide and maintain a level of system safety sufficient to permit routine use of the system in crew training operations while ensuring that safety measures do not adversely affect the performance of the system during its intended use in emergency scenarios. Human tolerance levels and stability under acceleration vary broadly depending on the axes of acceleration, restraint type, duration, and condition of the subjects. The limits in this requirement represent safe levels of translational acceleration and start and stop changes in acceleration or jerk for the human. Exposure to acceleration above these limits could cause injury.

** This requirement may be revised based on tailoring of ASTM F2291-20, Standard Practice for Design of Amusement Rides and Devices, to be more specific to human spaceflight system parameters.]*

Table 12.2-1—EES Acceleration Limits - Sustained

	NASA Category 0 Standing Unrestrained with Support Aids	NASA Category 1 Seated Unrestrained without Support Aids	NASA Category 2 Seated with Sufficient Support Aids	NASA Category 3 Seated with Restraints	NASA Category 4 Seated with Full Restraints
+/- Ax (Eyeballs In/Out)	|Ax| ≤ 0.3g	-0.3g ≤ Ax ≤ 1.8g If Az > 0.7g: -0.45g ≤ Ax ≤ 1.8g	-0.7g ≤ Ax ≤ 3.0g	-2.0g ≤ Ax ≤ 4.0g	|Ax| ≤ 4.0g
+/- Ay (Eyeballs Right/Left)	|Ay| ≤ 0.3g	|Ay| ≤ 0.3g If Az ≥ 0.7g: |Ay| ≤ 0.45g	|Ay| ≤ 1.0g	|Ay| ≤ 1.0g	|Ay| ≤ 1.0g
+/- Az (Eyeballs Down/Up) Gravity is +1.0g (Az)	0.7g ≤ Az ≤ 1.3g	0.2g ≤ Az ≤ 1.5g	0.2g ≤ Az ≤ 1.8g	-0.5g ≤ Az ≤ 2.0g If time > 30s: 0g ≤ Az ≤ 2.0g	-0.5g ≤ Az ≤ 2.0g If time > 30s: 0g ≤ Az ≤ 2.0g
NASA Category 0 - Support aids are handhold points such as straps or handgrips. Guidance derived from U.S. Department of Transportation (DOT) Standards, 49 CFR Part II, Parts 213 and 238, DOT, Federal Railway Administration: Vehicle/Track Interaction Safety Standards; High-Speed and High Cant Deficiency Operations; Final Rule March 13, 2013. Supplemental material from Hoberock, L.L. (1976). A survey of longitudinal acceleration comfort studies in ground transportation vehicles, U.S. Department of Transportation, Office of University Research, Research Report 40.					
NASA Category 1 - Assumptions are that passengers are seated with seatback and headrest. General guidance derived from ASTM F2291-20, Area 1. Supplemental material from: (1) Hoberock, L.L. (1976). A survey of longitudinal acceleration comfort studies in ground transportation vehicles, U.S. Department of Transportation, Office of University Research, Research Report 40; and (2) Abernethy, C.N., Plank, G.R., and Sussman, E.O. (1977). Effects of deceleration and rate of deceleration on live seated human subjects. U.S. Department of Transportation, Report No. UMTA-MA-06-004S-77-3.					
NASA Category 2 - Plus sufficient support aids are neck support with molded headrest and lateral supports/dividers. General guidance derived from ASTM F2291-20, Area 2.					
NASA Category 3 - Plus restraints are snug and padded for torso and shoulders.					
NASA Category 4 - Plus restraints hold neck securely with full body stabilization fore/aft and lateral.					
For the -Ax and +/-Ay requirements of NASA Category 1 and the -Ax requirement of NASA Category 2, it is assumed that the seat-suit interface has sufficient stiction and friction.					
When incapacitated personnel are placed in the vehicle, if they are restrained in a secured Stokes-type litter, then Category 3 acceleration limits apply.					
When incapacitated personnel are placed in the vehicle in a seated position, if Category 4 restraints are used, then Category 4 acceleration limits apply.					
In all other scenarios for incapacitated personnel, Category 0 acceleration limits apply, and appropriate methods should be used to minimize their motion during the ride.					
Verification will determine whether any of the sustained acceleration limits in above table are exceeded for more than 200ms for any passenger, given their assumed orientation and level of restraint. Per ASTM F2291-18, Section 7.1.1.2, all measured or simulated acceleration time histories will be postprocessed using a 4th-order, single pass, Butterworth low-pass filter with a corner frequency of 5 Hz.					

Table 12.2-2—EES Acceleration Limits - Jerk

	NASA Category 0 Standing Unrestrained with Support Aids	NASA Category 1 Seated Unrestrained without Support Aids	NASA Category 2 Seated Unrestrained with Sufficient Support Aids	NASA Category 3 Seated with Restraints	NASA Category 4 Seated with Restraints
dAx/dt	3g/s	10g/s	20g/s	30g/s	40g/s
dAy/dt	3g/s	3g/s	10g/s	10g/s	10g/s
dAz/dt	4.5g/s	10g/s	12g/s	20g/s	20g/s
Verification will determine whether any of the sustained acceleration limits in Table 37 are exceeded for more than 200 ms for any passenger, given their assumed orientation and level of restraint. Per ASTM-F2291-20, section 7.1.1.2, all measured or simulated acceleration time histories will be post processed using a 4th-order, single pass, Butterworth low-pass filter with a corner frequency of 5 Hz.					

APPENDIX A

REFERENCES

A.1 PURPOSE

This Appendix provides references to guidance documents related to this NASA Technical Standard. Reference documents may be accessed at https://standards.nasa.gov, obtained directly from the Standards Developing Body or other document distributors, obtained from information provided or linked, or by contacting the Center Library or office of primary responsibility.

The latest issuances of cited documents apply unless specific versions are designated.

A.2 REFERENCES

A.2.1 Government Documents

Department of Defense

SS521-AG-PRO-010	U.S. Navy Diving Manual
MIL-HDBK-1908	Definitions of Human Factors Terms
MIL-STD-1472	Department of Defense Design Criteria Standard, Human Engineering
MIL-STD-1474	Department of Defense Design Criteria Standard, Noise Limits
SS521-AG-PRO-010	U.S. Navy Diving Manual

Federal

29 U.S.C. §1915.12(a)(2), Precautions and the order of testing before entering confined and enclosed spaces and other dangerous atmospheres, March 28, 2017

49 CFR Part II, Parts 213 and 238, U.S. Department of Transportation (DOT) Standards, Federal Railway Administration: Vehicle/Track Interaction Safety Standards; High-Speed and High Cant Deficiency Operations; Final Rule March 13, 2013

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (UN, 1967), Article IX

Centers for Disease Control and Prevention (CDC)	Perceived Exertion (Borg Rating of Perceived Exertion Scale) https://www.cdc.gov/physicalactivity/basics/measuring/exertion.htm
Electronic Code of Federal Regulations	1910.146(b)(3), Permit-required confined spaces. Current through July 29, 2021
Environment, Health & Safety	Biological Exposure Indices® (BEIs), sections Light and Near-Infrared Radiation and Ultraviolet Radiation (2014 or later).
Occupational Safety and Health Administration (OSHA)	Policy on Indoor Air Quality: Office Temperature/Humidity and Environmental Tobacco Smoke, 2003 https://www.osha.gov/laws-regs/standardinterpretations/2003-02-24
OMB Circular No. A-119	Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities, as revised January 27, 2016, at Federal Register Vol. 81, No. 17, page 4673, accessible at https://www.whitehouse.gov/wp-content/uploads/2020/07/revised_circular_a-119_as_of_1_22.pdf
Electronic Code of Federal Regulations	1910.146(b)(3), Permit-required confined spaces. Current through July 29, 2021
The National Institute for Occupational Safety and Health (NIOSH)	Criteria For a Recommended Standard: Occupational Noise Exposure https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf?id=10.26616/NIOSHPUB98126
World Health Organization (WHO)	Exposure Criteria, Occupational Exposure Levels https://www.who.int/occupational_health/publications/noise4.pdf
Environment, Health & Safety	Biological Exposure Indices® (BEIs), sections Light and Near-Infrared Radiation and Ultraviolet Radiation (2014 or later).
Centers for Disease Control and Prevention (CDC)	Perceived Exertion (Borg Rating of Perceived Exertion Scale) https://www.cdc.gov/physicalactivity/basics/measuring/exertion.htm

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	Deliberations of the Exploration Atmospheres Working Group (EAWG), 2006
	Human Exploration and Operations Mission Directorate (HEOMD) memo, Exploration Atmospheres, February 2013
	Operational and Research Musculoskeletal Summit, August 23-25, 2005, Space Center, Houston, TX (https://ntrs.nasa.gov/api/citations/20070031573/downloads/20070031573.pdf)
	Nutrition Requirements, Standards, and Operating Bands for Exploration Missions, December 2005. Johnson Space Center, Scott M. Smith
EC-09-154	Bue, Grant C., Lyndon B. Johnson Space Center Memorandum, Tolerable Limit for Hand Skin Temperatures in Glove Tests, November 3, 2009
EHP-10028	Extravehicular Activity and Human Surface Mobility (EHP) Exploration EVA (xEVA) System Compatibility Standards
JPR 1830.6	Requirements Applicable to Personnel Participating in Diving, Hyper/Hypobaric Chambers, and Pressurized Suit Operations). Page 15, subsection 4.2: Limitations during Oxygen Breathing
JSC 27260	Standard Flight Decal Catalog (https://www.nasa.gov/centers/johnson/pdf/495093main_Decal-Catalog-JSC-27260-RevF.pdf)
JSC 27472	Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals to be Flown on Crewed Spacecraft (https://www.nasa.gov/sites/default/files/atoms/files/jsc_form_27472.pdf)
JSC 39116	EMU Phase VI Glove Thermal Vacuum Test and Analysis Final Report, Doc. #CTSD-SS-1621, NASA Johnson Space Center, August 20, 1998

JSC 63414	Spacecraft Water Exposure Guidelines (SWEGs) (https://www.nasa.gov/sites/default/files/atoms/files/jsc_63414_final_with_signature.pdf)
JSC 63557	Net Habitable Volume Verification Method
JSC 65995	Commercial Human Systems Integration Processes (CHSIP)
JSC 65829	Loads and Structural Dynamics Requirements for Space flight Hardware (https://ntrs.nasa.gov/api/citations/20110015359/downloads/20110015359.pdf)
JSC 66320	Optical Property Requirements for Glasses, Ceramics, and Plastics in Spacecraft Window Systems (https://forum.nasaspaceflight.com/index.php?action=dlattach;topic=51325.0;attach=1945174;sess=0)
JSC 67627	Pre-Launch and Post-Landing Food Service Operational Procedures
JSC-CN-19414	Assessment of Prone Positioning of Restrained, Seated Crewmembers in a Post Landing Stable 2 Orion Configuration (https://ntrs.nasa.gov/citations/20100005137)
JPR 1800.3	Decompression Sickness
JPR 5322.1	Contamination Control Requirements Manual
MSFC Form 4657	Change Request for a NASA Engineering Standard
NASA/SP-6105	NASA Systems Engineering Handbook (https://ntrs.nasa.gov/citations/20170007238)
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft
NASA-STD-8739	Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring
NASA/TM-2007-214755	The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations (https://ntrs.nasa.gov/citations/20070030109)

NASA/TM-2008-215198	The Use of a Vehicle Acceleration Exposure Limit Model and a Finite Element Crash Test Dummy Model to Evaluate the Risk of Injuries during Orion Crew Module Landings (https://ntrs.nasa.gov/citations/20080018587)
NASA/TM-2013-217380	Application of the Brinkley Dynamic Response Criterion to Spacecraft Transient Dynamic Events (https://ntrs.nasa.gov/citations/20170005913)
NASA/TM-2014-217383	Defining NASA Risk Guidelines for Capsule-based Spacecraft Occupant Injuries Resulting from Launch, Abort, and Landing
NASA/TM-2020-220525	Standard Testing Procedure for Quantifying Breathing Gas Carbon Dioxide Partial Pressure for Extravehicular Activity and Launch, Entry, Survival Pressure Suits (https://ntrs.nasa.gov/api/citations/20200002476/downloads/20200002476.pdf)
NASA/TM-2020-5008196	Artemis Sustained Translational Acceleration Limits: Human Tolerance Evidence from Apollo to International Space Station (https://www.nasa.gov/sites/default/files/atoms/files/lunar_transient_accel_tm.pdf)
NASA/TM-2022-0011974	Lunar Transport Vehicle Occupant Protection Requirements
NASA-TN-D-5153	The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities (https://ntrs.nasa.gov/citations/19690013177)
NASA/TP-2014-218556	Human Integration Design Processes (HIDP) (https://ntrs.nasa.gov/citations/20140009559)
NID 8715.129	Biological Planetary Protection for Human Missions to Mars
NPD 8020.7	Biological Contamination Control for Outbound and Inbound Planetary Spacecraft
NPR 7120.7	NASA Information Technology Program and Project Management Requirements
NPR 8715.3	NASA General Safety Program Requirements

SA-12-067	Level II Johnson Space Center (JSC) Chief Medical Officer (CMO) Health and Medical Technical Authority (HMTA) Position on Potential Atmospheres for Exploration, August 8, 2012
SA-16-156	Level II JSC CMO HMTA Position on NHV and Internal Layout Considerations for Exploration Missions
SSP 50260	International Space Station Medical Operations Requirements Document (MORD)
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APPENDIX B

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

B.1 PURPOSE

This Appendix provides guidance, made available in the acronym, abbreviation, and symbol definitions listed below.

B.2 REFERENCES

~	approximately
β	beta, injury risk criterion
°	degree
Δ	delta (change)
ΔQ	delta Q
=	equal
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
-	minus
μg	microgram
μ	mu, micro
μm	Micrometer
μPa	micropascal
Ω	omega, ohm
%	percent, percentile
+	plus
±	plus or minus
θ	theta, angle of incidence
ρ	rho, density
A	ampere
A/m	ampere per meter
AC	alternating current
ACGIH	American Conference of Governmental Industrial Hygienists
AF	activity factor
AGARD	Advisory Group for Aerospace Research and Development
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
APP	Applicable
Ar	Argon

AR	augmented reality
ARS	atmosphere revitalization system
ASCII	American Standard Code for Information Interchange
ASA	Acoustical Society of America
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
+/- Ax	Eyeballs in/out
+/- Ay	Eyeballs right/left
+/- Az	Eyeballs down/up
B/W	black and white
BEI	biological exposure index (indices)
BET	Blur Edge Time
bpm	beats per minute
BSL	biosafety levels
Btu	British thermal unit
c	specific heat
C	Celsius
cal	calorie
CCP	Commercial Crew Program
CCT	Correlated Color Temperature
cd	candela
CDO	cognitive deficit onset
CFE	Contractor Furnished Equipment
CFR	Code of Federal Regulations
CFU	colony forming unit
CGMP	Current Good Manufacturing Practices
CHSIP	Commercial Human Systems Integration Processes
CIE	International Commission on Illumination
cm	centimeter
cm^2	square centimeter
CMO	Chief Medical Officer
C_n	minutes of noise exposure
CO_2	carbon dioxide
COAS	Crew Optical Alignment System
Comm	Communication
COSPAR	Committee for Space Research
COTS	Commercial Off-the-Shelf
CP	combustion product
CQS	Color Quality Scale
CRI	Color Rendering Index
D	noise dose
dB	decibel
dBA	decibels, A-weighted
DC	direct current
DCS	decompression sickness

Deg	Degree
DER	Daylight Equivalent Ratio
DMS	Display Measurement Standard
DNA	deoxyribonucleic acid
DOT	Department of Transportation
DRI	dietary reference intake
DRM	Design Reference Mission
E	perceptual distance between colors electric field strength
EAWG	Exploration Atmospheres Working Group
ECG	electrocardiogram
ECLSS	Environmental Control and Life Support System
EDI	Equivalent Daylight Illuminance
EE	Extreme Environment
EER	estimated energy requirements
EES	emergency egress systems
EHP	Extravehicular Activity and Human Surface Mobility Program
EMU	extravehicular mobility unit
ETEC	Enterotoxigenic Escherichia coli
ESTV	Extraterrestrial Surface Transport Vehicle
ETA	estimated time of arrival Engineering Technical Authority
EVA	extravehicular activity
F	Fahrenheit
f	frequency
f_G	frequency in gigahertz
F_i	Fractional concentration of inspired oxygen
f_M	frequency in megahertz
FFRDC	Federally Funded Research and Development Center
fl	fluid
fl oz	fluid ounce
FOD	Foreign Object Debris
FPDM	Flat Panel Display Measurements
FSMA	Food Safety Modernization Act
ft	foot, feet
G	gravitational constant
g	gram gravity (gravity equals 9.8 m/s^2)
GCR	galactic cosmic ray
GET	Gaussian Edge Time
GFP	Government Furnished Equipment
GHz	gigahertz
GPS	Global Positioning System
GSE	Ground Support Equipment

GUI	graphical user interface
+/- Gx	See +/- Ax
+/- Gy	See +/- Ay
+/- Gz	See +/- Az
H	magnetic field strength
HCD	human-centered design
HDBK	Handbook
He	Helium
HEI	human error identification
HeNe	helium-neon
HEOMD	Human Exploration and Operations Mission Directorate
HEPA	high efficiency particulate air
HFDS	Human-System Interface Standard
HIDH	Human Integration Design Handbook
HIDP	Human Integration Design Processes
HITL	human-in-the-loop
HMTA	Health and Medical Technical Authority
HQR	Handling Qualities Rating
hr	hour
HRL	hazard response level
HSI	human systems integration
HSIP	Human Systems Integration Plan
HUD	head's up display
Hz	Hertz
ICDM	International Committee on Display Metrology
ICR	Incapacitated Crew Rescue
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IMV	inter-module ventilation
in	inch
IPR	intellectual property rights
IR	infrared
IRD	Information Requirements Document
ISO	International Organization for Standardization
ISS	International Space Station
IVA	intravehicular activity
J	Joule
JPR	Johnson Procedural Requirements
JSC	Johnson Space Center
K	Kelvin
k	kilo
	thermal conductivity
kcal	kilocalorie
kg	kilogram

kHz	kilohertz
kJ	kilojoule
km	kilometer
kPa	kilopascal
L	liter
LADTAG	Lunar Atmosphere Dust Toxicity Assessment Group
lb	pound
LEA	launch, entry and abort
LED	light-emitting diodes
LEO	low Earth orbit
LIA	Laser Institute of America
LiOH	lithium hydroxide
L_n	sound level of a noise exposure event in dBA
LN,A	A-weighted sound level of the ambient noise
LOC	loss of crew
logMAR	Logarithm of the Minimum Angle of Resolution
LOM	loss of mission
LRU	Line Replacement Unit
LS,A	A-weighted sound level of the auditory annunciation or signal
LSi,oct	Octave band sound pressure level corresponding to the auditory annunciation or signal
LSi, 1/3oct	1/3 octave band sound pressure level corresponding to the auditory annunciation or signal
Lti,1/3oct	1/3 octave band sound pressure level corresponding to the effective masked threshold
m	meter
m^3	cubic meter
MΩ	megaohm
mA	milliampere
ma	maximum current
Max	maximum
MET	Mission Elapsed Time
mg	milligram
MHz	megahertz
MI	maintenance item
MIL	Military
min	minute
mL	milliliter
mm	millimeter
MH	Monomethyl hydrazine
MMH	Manual Materials Handling
mmHg	millimeter of mercury
MMOD	Micrometeoroids and Orbital Debris
MORD	Medical Operations Requirements Document

MPE	maximum permissible exposure
ms	millisecond
MSFC	Marshall Space Flight Center
N	number of noise exposure events in a 24-hour period
N_2	Nitrogen
N/A	not applicable
NASA	National Aeronautics and Space Administration
NC	noise criterion
	normal condition
NEMA	National Electrical Manufacturers Association
NHV	Net habitable volume
NIOSH	National Institute for Occupational Safety and Health
nm	nanometer
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
O_2	oxygen
OCHMO	Office of the Chief Health and Medical Officer
Oct	octave
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
oz	ounce
Pa	Pascal
PA	potentially applicable
PB	Ambient Barometric Pressure
PDA	personal digital assistant
PEL	permissible exposure limit
PET	Phased Elapsed TIme
P_ICO_2	inspired carbon dioxide partial pressure
P_IO_2	inspired oxygen partial pressure
pp	partial pressure
ppm	parts per million
$ppCO_2$	partial pressure of carbon dioxide
PPE	Personal Protective Equipment
ppO_2	partial pressure of oxygen
psi	pound(s) per square inch
psia	pound(s) per square inch absolute
PWD	potable water dispenser
Q	heat
rad/s^2	radians per second squared
REID	risk of exposure-induced death
RF	radio frequency
Rg	color gamut index
RH	relative humidity
RMS	root mean square
RPE	Rating of Perceived Exertion

rpm	revolutions per minute
s	second
S	power density
SA	situational awareness
SAS	space adaptation syndrome
SDS	Safety Data Sheet
sec	second
SI	International System of Units
SIL	speech interference level
SMAC	spacecraft maximum allowable concentration
SP	special publication
SPE	solar particle event
SPL	sound pressure level
SRD	System Requirements Document
SSP	Space Station Program
STD	Standard
STS	Space Transportation System
SUS	system usability scale
SWEG	spacecraft water exposure guideline
TLV	threshold limit value
TM	technical memorandum
T_n	maximum noise exposure duration allowed
TP	technical publication
TWA	time-weighted average
UDMH	unsymmetrical dimethylhydrazine
UN	United Nations
U.S.	United States
UV	ultraviolet
u'v'	uniform-chromaticity scale (CIE 15.2, Colorimetric 2nd ed. Commission International d l' Cellarage, Vienna Austria 1986)
V	Volt volume
V/m	volt(s) per meter
V1	Volume 1 (in designating numbered requirements)
V2	Volume 2 (in designating numbered requirements)
VESA	Video Electronics Standards Association
VGE	venous gas emboli
VOC	volatile organic compound
V_u	urinary output volume
W	watt
WHC	waste and hygiene compartment
WHO	World Health Organization
W/m	watt(s) per meter
W/m^2	watt(s) per meter squared

xEVA	Exploration EVA
y	year

APPENDIX C

DEFINITIONS

C.1 PURPOSE

This Appendix provides guidance, made available in the definitions listed below.

C.2 DEFINITIONS

Accessibility: A design feature referring to the ability to see and maneuver within a spatial volume for the purpose of operating, cleaning, retrieving, or maintaining parts of a subsystem.

Activity Center: A specific location uniquely configured for a human activity such as personal hygiene, body waste, food, sleep, trash, stowage, and exercise countermeasures.

Acute Field of View: The region of visual angle in which acuity remains at least half its maximum. It is about 3 degrees in diameter.

Advisory: A message that indicates a safe or normal configuration, indicates safe or normal operation of essential equipment, or imparts information for routine action purposes.

Affect: Observable behavior that represents the expression of a subjectively experienced feeling state (mood, morale). Common examples of affect are sadness, fear, joy, and anger. The normal range of expressed affect varies considerably between different cultures and even within the same culture.

All Mission Systems: Includes terrestrial ground control centers, other spacecraft on an occupied planetary body, other orbiting spacecraft, and other locations onboard a spacecraft.

Ambient: The portion of the atmosphere, external to buildings, to which the general public has access.

Anthropogenic: Induced or altered by the presence of humans.

Anthropometry: The science of measuring the human body and its parts and functional capabilities. Includes lengths, circumferences, body mass, etc.

Astronaut: An individual selected and trained to travel into space and to monitor, operate, and control parts of, or the whole space system to complete mission objectives.

Atmospheric Conditions: The composition of the invisible gaseous substances within the vehicle/habitat (e.g., nitrogen, oxygen, argon, carbon dioxide) as well as the pressure, temperature, humidity, particulates and contaminants, etc.

Attenuation: Diminution in force or intensity of sound.

Automatic: Pertaining to a function, operation, process, or device that, under specified conditions, functions without intervention by the crew.

Automation: (1) The implementation of a process by automatic means. (2) The theory, art, or technique of making a process more automatic. (3) The investigation, design, development, and application of methods of rendering processes automatic, self-moving, or self-controlling.

Autonomous: The combination of elements that function together to produce the capability to meet a need that under specified conditions, functions without intervention by a human. Note: the elements of an autonomous systems include all hardware, software, equipment, facilities, personnel, processes, and procedures needed to function.

Beam Distribution: Represents a ¼π hemisphere or ½π spherical characterization of the intensity of light at multiple angles from the source. Typically, illuminance measurements are captured at a fixed radius at multiple angles. Beam distribution is usually reported in relative percent intensity per angle with estimated lumen output, candela per angle, or illuminance per radius per angle.

Biomechanics: The study of the principles and relationships involved with muscular activity.

Blur Edge Time (BET): A measure of the amount of motion blur on an electronic display, especially liquid crystal display. This metric is defined in ICDM-DMS 1.0.

Body-Referenced Interfaces: Interfaces that are controlled by the dynamic movements of the human body such as virtual environments.

Broad Spectrum: A spectrum or list of a sufficient number of target compounds anticipated from all expected off-nominal events.

Capability: Having attributes (such as physical or cognitive) required for performance.

Catastrophic: (1) A hazard that could result in a mishap causing fatal injury to personnel and/or loss of one or more major elements of the flight vehicle or ground facility. (2) A condition that may cause death or permanently disabling injury, major system or facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission (NPR 8715.3, NASA General Safety Program Requirements).

Caution: Notification of an event that needs attention but not immediate action.

Chromaticity: Describes the color of an object, whether that be a surface material or light source. Chromaticity cannot be estimated without the usage of a spectrophotometer to measure the spectral power distribution of a light emitting source spectrum of a material. It is a calculated metric where the format of the units can be different depending on which standard is used.

Cleaning: Physical removal of dust, microbes, marks, or other impurities, from the habitat/suit by washing, wiping, or disinfecting.

Clear Viewing Aperture: The area of a window that is not covered by the window assembly frame or other structure that would block incident light rays.

Cognitive: Pertaining to the mental processes of perception, learning, memory, comprehension, judgment, and reasoning.

Color Discrimination: The ability to distinguish between pairs of colors that span the space of colors under standard viewing conditions. The International Commission on Illumination (CIE) has defined ΔE units that specify the perceptual distance between colors.

Color Fidelity: Describes the ability of a light source to render the appearance of colored materials accurately. The ideal case for comparison is how the Sun renders the color of materials. Color fidelity cannot be estimated without the usage of a spectral radiance or spectral irradiance meter to measure the spectral power distribution of a light emitting source. It is a calculated metric where the format of the units can be different depending on which standard is used.

Communication Systems: Communication systems include information provided to and from the crew by way of voice, text, video, and/or telemetry.

Consistency: The level of similarity in visual style and operation within and among different crew interface designs. Systems that have been designed with consistency in mind require less training and feel familiar. The number of different codes and ways of operating are minimized, which reduces cognitive workload and operational errors. Cross-system consistency is achieved by incorporating threads of similarity in key components across designs. Higher levels of consistency across vehicles will decrease the risk of errors and result in a safer spacecraft environment.

Contamination: The act of rendering unfit for use by the introduction or deposition of unwholesome or undesirable, usually foreign, elements.

Contamination control: The practice of controlling the introduction and removal of unwanted materials that could impede the proper function of a system or component (e.g., clean rooms, visual inspection, off-gassing minimization, flushing of fluid lines). While contamination control measures often serve to reduce the risk of forward contamination for planetary production, their ultimate goal is to improve system function.

Contingency: An off-nominal situation that is identified in the hazard analysis process and has a preplanned response to mitigate the risks to crew and/or vehicle.

Continuous Noise: Noise that exists in a steady state for durations of more than 8 hours in a 24-hour period. Typical continuous sources of noise include environmental control equipment and avionics equipment (e.g., fans, pumps, ventilation systems).

Countermeasures: A means to offset undesirable physical, physiological, and psychological effects of spaceflight on humans.

Corrective Maintenance: Corrective maintenance involves the repair or replacement of equipment that has stopped working or is damaged. Corrective maintenance activities include identifying, isolating, and rectifying a fault so that the failed equipment, machine, or system can be restored to an operational condition.

Crew: Team of two or more crewmembers assigned to a mission that have been trained to monitor, operate, and control parts of, or the whole space system.

Crewmember: An individual member of a crew.

Crew Station: A location in a vehicle or habitat where crewmembers perform an activity.

Critical: A condition that may cause severe injury, occupational illness, or major property damage to facilities, systems, or flight hardware (NPR 8715.3); also of essential importance, vital, or indispensable as in "critical" design parameters. Frequently used in this NASA Technical Standard to cover both "critical" (as defined above) and "catastrophic."

Decompression: The act or process of reduction of pressure, as occurs when releasing compressed air from a vehicle or habitat to the vacuum of space.

Decompression Sickness: A sickness induced by too rapid a decrease in atmospheric pressure sufficient to cause bubbles to form from gases (normally nitrogen [N_2]) dissolved in blood and other body tissues.

Deconditioned Crew (deconditioning): Decreased functionality of physiological systems, e.g., musculoskeletal, cardiovascular, vestibular, and nervous systems, related to adaptation to reduced gravity.

Dedicated Equipment Work Volume: Volume that cannot have multi-use but must be associated full-time with the equipment (such as interior volume of glove box, etc).

Depressurization: Reducing the pressure of air or gas within a suit, chamber, or vehicle.

Dexterity: The skill in performing tasks, especially with the hands whether suited or unsuited.

Diffusion/Diffusor: A material designed to scatter or redirect light that passes through it. Alternatively, a rough surface that light impacts and scatters multiple directions from.

Diffuse Reflectance: The fraction of incident electromagnetic radiation such as light or other type of wave within a specified wavelength band that is reflected from a surface uniformly in all directions, regardless of the angle of incidence of the incident waves or rays. A truly diffusely (Lambertian) reflective surface has the same luminance (appears to have the same brightness) from all viewpoints, regardless of the direction of the source relative to the surface. This type of reflection is associated with matte or “flat” surface treatments on objects and is contrasted with specular reflectance. Most surfaces exhibit a combination of specular and diffuse reflectance.

Display: Anything that provides visual, auditory, and/or haptic information to crewmembers, e.g., label, placard, tone, or display device. The term “display” includes text-based user interfaces, as well as Graphical User Interfaces (GUIs).

Display Device: The hardware used to present visual, aural, and tactile information to the crew or ground operations personnel. Display devices include computer monitors and Personal Digital Assistants (PDAs).

Doors: A moveable physical barrier that acts to provide physical separation between areas or to provide privacy. Examples of doors include enclosures for an unpressurized payload bay, or a privacy divider for a personal crew quarter or hygiene area.

Doorway: The opening, the area of the vehicle, that houses the doors.

Drag Through: Any item that inhibits hatchway function by interfering with the clear passage through the hatchways including, but not limited to, cargo, cables, and wires.

ECLS System: Environmental Control and Life Support (ECLS) Systems designed to distribute air and remove contaminants. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.

Effective Masked Threshold: The level of auditory danger signal just audible over the ambient noise, taking account of the acoustic parameters of both the ambient noise in the signal reception area and the listening deficiencies (hearing protection, hearing loss, and other masking effects). The method for calculating the masked threshold is given in ISO 7731:2003(E) Annex B.

Emergency: Time-critical event that requires immediate action and procedures to prevent loss of crew/loss of mission (LOC/LOM).

Emergency Equipment: A set of components (hardware and/or software) used to mitigate or control hazards, after occurrence, which present an immediate threat to the crew or crewed spacecraft. Examples include fire suppression systems and extinguishers, emergency breathing devices, and crew escape systems (NPR 8705.2).

Emergency Only Controls: Controls that are only used during emergencies, e.g., eject, abort.

Environmental Conditions: Nominal or off-nominal conditions within the vehicle that includes air, water, contamination, acceleration, acoustics, vibration, radiation, temperature, atmosphere, pressure, humidity, ppO_2, $ppCO_2$, etc.

Equipment: Items such as tools used to accomplish a task or activity. Equipment is a type of hardware, and therefore this term is sometimes used interchangeably with hardware.

EVA Spacesuit System: Any spacesuit system designed to allow astronauts to perform tasks outside of a spacecraft or habitat. Performance of spaceflight EVA consists of placing a human in a micro-environment that has to provide all the life support, nutrition, hydration, waste, and consumables management function of an actual space vehicle, while allowing crewmembers to perform mission tasks. EVA spacesuits are designed to be used for durations of less than a day due to potential human and suit system constraints. This includes all suited phases (e.g., prebreathe, leak checks, airlock depress, repress).

Exercise: Any bodily activity that enhances or maintains physical fitness and overall health and wellness. Exercise is used to maintain or minimize loss of crew muscle mass and cardiovascular fitness, to maintain muscle mass and strength/endurance, for recovery from strenuous tasks and confined postures, to rehabilitate minor muscle injuries, and to maintain bone mass. Exercise also has behavioral health benefits.

Extraterrestrial: To be from outside Earth or its atmosphere (moon, planetary, asteroid, etc.).

Extravehicular Activity: Operations performed by suited crew outside the pressurized environment of a flight vehicle or habitat (during spaceflight or on a destination surface). Includes contingency operations performed inside unpressurized vehicles or habitats.

Fatigue: Weariness, exhaustion, or decreased attention related to labor, exertion, or stress. May also result from lack of sleep, circadian shifts, depression, boredom, or disease. May result in decreased ability to perform mental or physical tasks.

Fault: An undesired system state and/or the immediate cause of failure (e.g., maladjustment, misalignment, defect, or other). The definition of the term "fault" envelopes the word "failure," since faults include other undesired events such as software anomalies and operational anomalies (Source - MIL-STD-721C). Faults at a lower level could lead to failures at the higher subsystem or system level.

Field of Regard: The solid angle that can be seen by an observer with eye and head movements.

Field of View: The solid angle that can be seen at one time by the stationary eye. It is about 150 degrees horizontally by 125 degrees vertically. When the two eyes operate together, the horizontal extent enlarges to about 190 degrees.

Field of View for Windows: All points through a window that can be viewed directly by at least one eye, given the combination of achievable eye, head, and body movement. The field of view is restricted by obstructions imposed by the facial structure around the eye and/or placed in front of the eye such as the crewmember's helmet if worn, mullions, structure, and/or other equipment. Achievable movement varies for different flight phases and operational tasks and is dependent on any constraints to movement that are extant such as being suited, seated, and/or restrained, and any g-loads present. With respect to line-of-sight phenomena such as contamination deposition and pluming, any point outboard of the window that is above the plane of the outer surface of the outermost pane of the window port is considered within the field of view of the window.

Food System: The interconnected network of activities and resources involved in providing nutrients for human nourishment and sustaining life. A food system includes the production, aggregation, processing, packaging, distribution, consumption, and disposal of food. In spaceflight to date, the food system can be defined as all foods, beverages, vitamins, supplements, and associated packaging and utensils, as well as support for preparation such as water dispensers and food warmers.

Gaussian Edge Time (GET): A measure of the amount of motion blur on an electronic display, especially a liquid crystal display. This metric is defined in ICDM-DMS 1.0.

Glare: A property that describes various problems in human perception of light and the interaction of light with surfaces and materials within an operational environment. Distracting glare is an "annoyance" where, because of reflection and refraction, it creates visual artifacts making it harder to see and resolve an object. Discomforting glare is caused by bright, directed, and reflected light that makes it hard to look at the object because of the brightness level. Disabling glare causes objects to appear to have lower contrast because of scatter inside the eye. Blinding glare is caused by a direct or indirect light source and is so bright that the observer cannot see or is visually compromised.

Ground Support Personnel: Human team of one or more members supporting a mission from the ground during preflight, in-flight, surface, and post flight operations.

Ground Support Operations: Operations and tasks performed by ground personnel utilizing spaceflight systems, hardware, and equipment at times other than during spaceflight such as before launches and after landings.

Habitability: The state of being fit for occupation or dwelling. Meeting occupant needs of health, safety, performance, and satisfaction.

Habitat: A type of spacecraft, not normally mobile, that has the conditions necessary to sustain the life of the crew and to allow the crew to perform their functions in an efficient manner.

Habitable Atmosphere: The composition of the breathable environment within the Habitable Volume.

Habitable Volume: The measure of space livable and functionally usable to crew within a pressurized volume after accounting for all installed hardware and systems.

Hardware: Individual components of equipment, including but not limited to, fasteners, panels, plumbing, switches, switch guards, and wiring. This term is sometimes used interchangeably with equipment.

Hatch: An operable, sealable cover that separates two adjoining environments and allows physical passage of people and/or material from one environment to the other. Hatches can maintain pressurized environments. Hatches may function as ingress/egress points for crew prior to launch, postlanding, and for EVAs, and may also serve as connections between modules in a spacecraft.

Hatch Cover: A protective encasement that protects the hatch from unwanted exposure.

Hatchway: The opening, the area of the vehicle that houses the hatch.

Heat Storage: Related to the human body as the balance of heat gains and heat losses; heat in minus heat out.

Human Error: Either an action that is not intended or desired by the person or a failure on the part of the person to perform a prescribed action within specified limits of accuracy, sequence, or time that does not produce the expected result and has led or has the potential to lead to an unwanted consequence.

Human Factors: The scientific discipline concerned with the understanding of interactions among humans and other elements of a system and the profession that applies theory, principles, data, and other methods to design to optimize human well-being and overall system performance.

Human-Rating Certification: Human-Rating Certification is the documented authorization granted by the NASA Administrator that allows the program manager to operate the space system within its prescribed parameters for its defined reference missions. Human-Rating Certification is obtained prior to the first crewed flight (for flight vehicles) or operational use (for other systems).

Impulse Noise: A burst of noise, which exists for 1 second or less, that is at least 10 dB above the background noise.

Information Management: The act of performing functions with electronic data, including data input, organization, internal processing, storage, distribution, saving, and disposal of information about the system. Information management functions are typically performed by crew and ground personnel using displays on display devices.

Interpretable: Capable of being explained or told the meaning of; translated into intelligible or familiar language or terms.

Ionizing Radiation: Any combination of electromagnetic radiation or particles that deposits enough kinetic energy to create ionization events when interacting with matter. Ionizing radiation energy absorption damages biological systems that may lead to clinical illness or contribute to human health and performance decrements.

In-Mission: Covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back to earth and post-landing activities.

Intravehicular Activity: Operations performed by crew within the pressurized environment of a spacecraft during a mission.

Intermittent Noise: Noise that is generated for operational durations of 8 hours or less in a 24-hour period. Typical intermittent sources of noise are waste control system components (pumps, fans, separators, valves), exercise equipment (treadmill, cycle ergometer), galley fans, personal hygiene station components (pumps, fans, valves), and pressure regulators.

Lambertian Reflectance: An 'ideal' reflectance property where incident light is reflected and scattered with equal energy at all angles from the surface (2π steradians). The appearance of such a material is described as diffuse or matte in finish.

LEA/IVA Spacesuit System: Any spacesuit system designed for use during launch, entry, and abort phases of spaceflight, primarily to protect against toxic exposure, ebullism, hypoxia, and decompression sickness in the event of an unplanned cabin depressurization or toxic release into the cabin. It may also be worn during other dynamic phases of flight such as rendezvous and docking during which there is an increased risk of cabin depressurization due to cabin leaks. The duration for which LEA spacesuits are designed to operate will depend on mission scenarios and may range from a few hours to several days per use.

Linear Acceleration: The rate of change of velocity of a mass, the direction of which is kept constant.

Local Vertical: Achieved by a consistent arrangement of vertical cues within a given visual field to provide a definable demarcation at the crew station boundary within the visual field. A consistent local vertical within modules is highly desirable.

Maintainability: Maintainability is a quality that reflects the speed and ease with which an operational system can be retained in, or restored to, a specified condition (Department of Defense (DoD), 1997). (Reference: Department of Defense. (1997). Designing and Developing Maintainable Products and Systems (Report No. MIL-HDBK-470A)).

Maintenance: All actions necessary for retaining material in (or restoring it to) a serviceable condition. Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, condition determination, corrosion control, and initial provisioning of support items (MIL-HDBK-1908B, Definitions of Human Factors Terms).

Mission: A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution.

Mission Duration: The total time the crew is away from the surface of Earth, measured from launch of the Earth launch vehicle to landing or splashdown of the Earth return spacecraft. If the crew transfers between multiple spacecraft during this mission, except where indicated otherwise in these technical requirements, every spacecraft the crew inhabits is subject to the requirements identified for the mission duration.

Mobility: The ability to move or be moved freely and easily whether suited or unsuited.

Monitoring: Includes checking for quality or fidelity; testing to determine if a signal comes within limits; watching and observing for a specific signal or purpose; keeping track of, regulating, or controlling.

Net Habitable Volume (NHV): The functional volume left available on a spacecraft after accounting for the loss of volume caused by deployed equipment, stowage, trash, and any other items that decrease the functional volume.

Noise: Sound in the auditory range (15 Hz to 20,000 Hz) that is hazardous, undesired, and/or inappropriate to the intended use of the space. In this NASA Technical Standard, the word "noise" is used interchangeably with “sound” and is not intended to convey any relative or absolute degree of hazard or other acoustical characteristic.

Nominal: Within expected, acceptable operational limits or in accordance with planned operational concepts; normal, satisfactory (aerospace usage).

Non-Habitable Volume: The portion of Pressurized Volume taken up by fixed outfitting, equipment, stowage, and dedicated equipment work volumes.

Non-Ionizing Radiation: Includes three categories of electromagnetic radiation: RF radiation, lasers, and incoherent electromagnetic radiation.

Off-Nominal: Outside of expected, acceptable operational limits or not in accordance with planned operational concepts; anomalous, unsatisfactory (aerospace usage).

Operation: An activity, mission, or maneuver, including its planning and execution.

Perception: The process of acquiring knowledge about environmental objects and events by extracting and processing the information received through the senses.

Personal Protective Equipment (PPE): Equipment that is worn to minimize exposure to a variety of hazards. Examples of PPE include such items as gloves, foot and eye protection, hearing protection devices (earplugs, muffs), hard hats, respirators, and full body suits.

Planetary Protection: The practices of reducing biological forward contamination that could affect astrobiological investigations on other celestial bodies and backward contamination that might have adverse impacts on Earth's biosphere.

Potable Water: Water that is suitable, safe, or prepared for drinking.

Pressurized Volume: The total volume within a pressure shell.

Preventive Maintenance: Preventive maintenance is maintenance that is regularly performed on a system to lessen the likelihood of it failing. Preventive maintenance can be schedule- or time-based, meaning the maintenance is performed routinely on a fixed schedule, or condition-based, meaning the maintenance is performed, on contingency, depending upon the condition of the equipment or system.

Privacy: Having an acceptable level of control over the extent of sharing oneself (physically, behaviorally, or intellectually) with others. Acceptable level is dependent upon an individual's background and training.

Program: A strategic investment by a Mission Directorate or Mission Support Office that has a defined architecture and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects. A program defines a strategic direction that the Agency has identified as critical.

Project: A spaceflight project is a specific investment identified in a Program Plan having defined requirements, a life-cycle cost, a beginning, and an end. A project also has a management structure and may have interfaces to other projects, agencies, and international partners.

Psychomotor: Of or relating to muscular action believed to ensue from conscious mental activity.

Reflectance: The fraction or percentage of incident electromagnetic radiation such as light or other type of wave at a specified wavelength that is reflected from a surface. (See also "specular reflectance" and "diffuse reflectance.")

Reflectance/Reflector (Light): The property of a material to reflect and scatter light. Reflectance of surface materials is an important lighting system property as it impacts how humans and cameras observe the environment and the efficiency of lighting systems to illuminate surfaces to sufficient levels to create the desired luminous contrast. Reflectance can be considered part of the architecture and can be used as a tool in the form of a reflector.

Regolith: Unconsolidated residual or transported material that overlies the solid rock on the Earth, Moon, or a planet.

Risk: Outcomes of programmatic decisions, proposed implementation, pursuit of standards/requirements deviations, and/or waivers that do not change the overall likelihood and consequence of the health, medical, and human performance risks baselined by Chief Health and Medical Officer (CHMO) for a particular program or project. In the context of mission execution, risk is operationally defined as a set of triplets:

a. The scenario(s) leading to degraded performance with respect to one or more performance measures (e.g., scenarios leading to injury, fatality, destruction of key assets; scenarios leading to exceedance of mass limits; scenarios leading to cost overruns; scenarios leading to schedule slippage).
b. The likelihood(s) (qualitative or quantitative) of those scenarios.
c. The consequence(s) (qualitative or quantitative severity of the performance degradation) that would result if those scenarios were to occur.
d. Uncertainties are included in the evaluation of likelihoods and consequences.

Rotational Acceleration: The rate of change of angular velocity.

Safe: Freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.

Scheduling: Arranging, controlling, and optimizing work and workloads to facilitate crew timeline of activities.

Sensory: The information-gathering abilities of humans to see, hear, touch, smell, and taste. Includes temperature, pain, kinesthesia, and equilibrium.

Shielding: A barrier between a source of radiation and a potential recipient (e.g., the astronaut); shielding can be solid, liquid, or gas which absorbs the energy of the radiation.

Situational Awareness: Comprehension of information about an environment, evaluating the current situation with respect to goals, and projecting the evolution of the situation into the future.

Solid Angle: The volumetric angular section from a unit sphere, analogous to the trigonometric concept of the unit circle. Units are in steradians (sr). An entire sphere equals 4π sr.

Sound Quality: Those features of a sound that contribute to the subjective impression made on a listener, with reference to the suitability of the sound for a particular set of design goals. It is meant particularly to account for aspects of communication systems that are not quantifiable by intelligibility measurements.

Space System: The collection of all space-based and ground-based systems (encompassing hardware and software) used to conduct space missions or support activity in space, including, but not limited to, the crewed space system, space-based communication and navigation systems, launch systems, and mission/launch control. Also referred to as "system" in the technical requirements.

Spacecraft: A habitable vehicle or device, including, but not limited to, orbiters, capsules, modules, landers, transfer vehicles, surface transport vehicles, EVA suits, and habitats designed for travel or operation outside Earth's atmosphere.

Spaceflight: A process that begins when the crew has boarded the spacecraft on Earth and the hatch is closed and terminates when the spacecraft has returned to Earth, and all of the crew have egressed the spacecraft and are in the care of ground personnel. In the event of a launch abort, spaceflight continues until all crew have been returned to the care of ground personnel.

Spatial Contrast Sensitivity: Defined by the inverse of the smallest contrast of a spatial sinusoidal luminance grating that can be detected, at each spatial frequency, under standard viewing conditions. Peak contrast sensitivity is about 500, and the highest frequency visible is about 60 cycles/deg.

Spectral Irradiance: Radiometric unit, analogous to illuminance, representing the radiant flux per surface area per wavelength. Units are in watts/meter^2/nanometer (W/m^2/nm).

Spectral Power Distribution: Waveform representing energy (absolute or relative) emitted per a range of wavelengths. All light sources have a unique spectral power distribution.

Spectral Radiance: Radiometric unit, analogous to luminance, representing the radiant flux per surface area per wavelength. Units are in watts/steradian/meter^2/nanometer (W/sr/m^3/nm).

Specular Reflectance: The perfect, mirror-like reflection of an incident wave or ray such as light from a surface, in which the wave or ray from a single incoming direction is reflected into a single outgoing direction as described by Snell's Law (θi (theta i) = θr (theta r)). Diffuse reflection, on the other hand, refers to light that is reflected in a broad range of directions. (See "diffuse reflectance.") The most familiar example of the distinction between specular and diffuse reflection in the case of light waves would be glossy and matte paints or photo prints. While both finishes exhibit a combination of specular and diffuse reflectance, glossy paints and photo prints have a greater proportion of specular reflectance, and matte paints and photo prints have a greater proportion of diffuse reflectance. Anti-reflection coatings reduce the amount of light that is reflected from a given surface. Reflectance for an uncoated glass surface is ~4%, which yields ~8% for the two surfaces of a single "pane." Anti-reflective coatings can reduce the total reflectance to ~2% or less.

Standard: The definition of a "standard" is described as follows:

a. The term "standard," or "technical standard," includes all of the following:
    (1) Common and repeated use of rules, conditions, guidelines or characteristics for products or related processes and production methods, and related management systems practices;

(2) The definition of terms; classification of components; delineation of procedures; specification of dimensions, materials, performance, designs, or operations; measurement of quality and quantity in describing materials, processes, products, systems, services or practices; test methods and sampling procedures; formats for information and communication exchange; or descriptions of fit and measurements of size or strength; and,

(3) Terminology, symbols, packaging, marking or labeling requirements as they apply to a product, process, or production method.

b. “Performance standard” is a standard that states requirements in terms of required results, but without stating the methods for achieving required results; may define the functional requirements for the item, operational requirements, and/or interface and interchangeability characteristics; also may be viewed in juxtaposition to a prescriptive standard.

c. “Non-government standard” is a standard as defined above that is in the form of a standardization document developed by a private sector association, organization, or technical society that plans, develops, establishes, or coordinates standards, specifications, handbooks, or related documents.

Standardize: To make uniform.

Stereoscopic Depth Perception: The ability to distinguish objects at different depths as a result of their different positions (disparities) in the two eyes.

Stowage/Storage: The action or method of storing something for future use.

Suited: Wearing clothing that is designed to protect the crewmember from differences in environment such as pressure, atmosphere, acceleration, or temperature. “Suited” can refer to both pressurized and unpressurized pressure suits.

Surface: The outside part or uppermost layer of an object. This can include the inner surfaces of items, like the suit.

Sustained Accelerations: Events, linear or rotational, with a duration of greater than 0.5 seconds.

System: The combination of elements that function together to produce the capability to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. (Source: NPR 7120.7, NASA Information Technology and Institutional Infrastructure Program and Project Management Requirements.)

Tactility: The responsiveness to stimulation of the sense of touch whether suited or unsuited.

Tailoring: The process by which requirements are derived for a specific system. This process involves two steps:

a. Selecting applicable requirements - Not all requirements within a Standard may apply to all systems. Systems are defined by parameters such as the number of crewmembers, mission duration and operations, gravity environment, and EVA activities. Some requirements apply to only some parameters. For example, mission duration may influence the volume dedicated for certain crew functions such as crew sleep and hygiene. Or the operational gravity environment may influence which requirements are applicable such as a lunar surface transport vehicle would not have met the microgravity requirements.

b. Creating requirements that can be verified - Some requirements use general terms such as “effective.” When tailoring for a specific system, these terms are then defined with values that are objective and measurable. The tailored requirement has to comply with the intent of the general requirement. For example, analysis of a specific system may show that a critical task has to be performed in less than 20 seconds. In the tailoring process, the word “effective” would be replaced by words that limit critical task performance times to 20 seconds.

<u>Task</u>: A specific type, piece, or amount of work; a subset of an activity or job that is called out in a procedure.

<u>Team</u>: A collection of individuals who are assigned to support and achieve a particular mission. This can encompass both the spaceflight crew and ground support for a particular mission.

<u>Temporal Contrast Sensitivity</u>: A measure of the sensitivity to contrast (i.e., modulation depth) as a function of time. This can be achieved by presenting stimuli that vary sinusoidally over time; it is like presenting a grating pattern in time instead of space.

<u>Thermesthesiometer</u>: A device designed to measure the depth of burn injuries.

<u>Time-to-Effect</u>: Time between when a hazard or failure occurs and the effects are manifested (NASA, 2021; Kennedy Space Center Office of Safety and Mission Assurance, 2015).

<u>Time-to-Effect Margin</u>: Time between when a hazard or failure occurs and the effects are manifested (NASA, 2021; Kennedy Space Center Office of Safety and Mission Assurance, 2015).

<u>Toxic Exposure</u>: Contact with agents or substances that can affect the health and performance of the astronauts.

<u>Training</u>: The act of undertaking a course of instruction in skills, knowledge or fitness that relate to specific competencies needed for spaceflight missions. Training has specific goals of improving an individual or team's capability, capacity, and performance.

<u>Transient Accelerations</u>: Events, linear or rotational, with a duration of less than or equal to 0.5 seconds.

<u>Transilluminated</u>: Luminous indicator, label, or button, that is made luminous by placing a colored or translucent material in front of light source or lamp.

Transmittance: The fraction or percentage of incident electromagnetic radiation such as light at a specified wavelength that passes through a medium.

Uniformity: A property that is typically applied for surface illumination but can also be applied to the light emitting face of light sources. Uniformity is usually defined in the form of ratios such as maximum/minimum, and average/minimum with a defined sampling grid size. Uniformity is an important safety and usability metric to minimize human error due to uneven illumination. Uniformity is achieved through a combination of beam distribution design, lamp placement, and understanding of reflective surfaces for the operational area.

Unit of Equipment: A unit of equipment is an assemblage of items that may include modules, components, and parts that are packaged together into a single hardware package (FAA HF-STD-001-B, 2016).

Unsuited: Wearing the type of clothing that is ordinarily worn in the interior of a spacecraft, especially a habitat, and as might be worn on Earth.

Vehicle/Habitat: A mobile or static spacecraft with a pressurized atmosphere appropriate for sustained, unsuited survival and crew operations. The vehicle is a container, generally composed of multiple elements, used to transport persons or things to/from a location outside of Earth's atmosphere. (See "habitat" as defined above.) Includes all hardware and equipment within or attached to the pressurized environment.

Validation: Proof that the product accomplishes the intended purpose. May be determined by a combination of test, analysis, and demonstration.

Visual Accommodation: Defined by the change in optical power of the eye to bring objects at different distances into focus. In young observers, average accommodative power is about 15 diopters but declines to 0 by the age of 60.

Visual Acuity: Defined by the smallest letters that can be identified under standard viewing conditions. An average acuity for young adults is about -0.1 logMAR but declines with age.

Voluntary Consensus Standards: A type of standard developed or adopted by voluntary consensus standards bodies, through the use of a voluntary consensus standards development process defined in the definition of voluntary consensus standards bodies in this section. These bodies often have intellectual property rights (IPR) policies that include provisions requiring that owners of relevant patented technology incorporated into a standard make that intellectual property available to implementers of the standard on a non-discriminatory and royalty-free or reasonable royalty terms (and to bind subsequent owners of standards essential patents to the same terms). A standard that includes patented technology needs to be governed by such policies, which should be easily accessible, set out clear rules governing the disclosure and licensing of the relevant intellectual property, and take into account the interests of all stakeholders, including the IPR holders and those seeking to implement the standard. (Source: OMB Circular No. A-119.)

Voluntary Consensus Standards Body: A type of association, organization, or technical society that plans, develops, establishes, or coordinates voluntary consensus standards using a voluntary consensus standards development process that includes the following attributes or elements:

a. Openness: The procedures or processes used are open to interested parties. Such parties are provided meaningful opportunities to participate in standards development on a non-discriminatory basis. The procedures or processes for participating in standards development and for developing the standard are transparent.
b. Balance: The standards development process should be balanced. Specifically, there should be meaningful involvement from a broad range of parties, with no single interest dominating the decision making.
c. Due process: Due process **shall** include documented and publicly available policies and procedures, adequate notice of meetings and standards development, sufficient time to review drafts and prepare views and objections, access to views and objections of other participants, and a fair and impartial process for resolving conflicting views.
d. Appeals process: An appeals process **shall** be available for the impartial handling of procedural appeals.
e. Consensus: Consensus is defined as general agreement, but not necessarily unanimity. During the development of consensus, comments and objections are considered using fair, impartial, open, and transparent processes. (Source: OMB Circular No. A-119).

Waiver: A written authorization allowing relief from a requirement.

Warning: Notification of an event that requires immediate action.

Wavefront: The surface joining all adjacent points on a wave that have the same phase, particularly light that travels as an electromagnetic wave.

Wavefront Error: The total optical path difference induced into a wavefront with respect to the wavelength of light, usually referenced to a helium-neon (HeNe) laser wavelength of 632.8 nm. For planar waves, wavefront error occurs when the wavefront is distorted such that an individual wavefront is no longer in phase. This occurs when different parts of the wavefront travel different optical path lengths. In an ideal window, a planar wave will pass through it such that the optical path length at each point on the window is the same, and the wavefront retains the same phase. Wavefront error is aperture dependent. In an imperfect window, the wavefront is distorted, i.e., the phase is not maintained. Wavefront error can be distorted by surface imperfections (the window is not “flat”) or by material inhomogeneities (the index of refraction varies across the window).

Window: A non-electronic means for direct through-the-hull viewing using a transparent material; the same as and used interchangeably with window port and window assembly.

Window Assembly: The same as and used interchangeably with window and window port.

Window Cover: An internal non-pressure-containing, transparent sheet or pane, usually of a different material than the windowpanes such as acrylic or other material intended to protect the underlying window pressure and/or protective pane(s) from incidental crew contact. A window cover is normally not an integral part of the window assembly and has the characteristics as specified in section 8.6, Windows, of the HIDH. Non-integral protective panes can be considered temporary, i.e., replaceable after some period of time, after which their optical quality has degraded below the category level for which they were designed. External window protection devices are referred to as shutters.

Window Filter: An internal, non-pressure-containing, transparent sheet or pane, usually of a different material than the windowpanes such as polycarbonate or other material intended to filter non-ionizing radiation hazards to safe levels. A window filter is not considered an integral part of the window assembly. Window filters are easily removed and reinstalled without the use of tools by one crewmember. A window filter may also serve as a window cover.

Window Port: The finished assembly, including the frame structure (includes all gaskets, bolts, spacers, and other such parts) and all windowpanes that would normally be used at a specific location with any protective panes, permanent coatings, plastic films, or laminates applied or in place; the same as and used interchangeably with window and window assembly.

Window Shade: Usually, an internal, non-pressure-containing, opaque sheet intended to block external light from entering the interior of a crew cabin. A window shade may or may not be an integral part of the window assembly. Non-integral window shades are easily removed and reinstalled without the use of tools by one crewmember. Window shades that are an integral part of the window assembly can also act as window shutters.

Window Shutter: An internally and remotely operable external cover intended to prevent natural and induced environmental degradation, e.g., contamination, erosion, and impacts, of the outboard-most windowpane with open and close indicators that are readable from the remote operating location. Window shutters can be operated through their full range of motion in less than 10 seconds and can serve as window shades.

Workload: The amount of work expected in a unit of time. Physical workload refers to the number of individual physical activities that are conducted simultaneously or in close succession. Similarly, mental or cognitive workload refers to the number of mental operations or activities that are conducted simultaneously or in close succession.

Worksite: Area defined as the operational space for a task to be performed. This can be as small as the area immediately in front of a work stand and can also encompass a large operational area that has the same task performance constraints.

APPENDIX D

REQUIREMENTS COMPLIANCE MATRIX

D.1 PURPOSE

Due to the complexity and uniqueness of spaceflight, it is unlikely that all of the requirements in a NASA Technical Standard will apply. The Requirements Compliance Matrix below contains this NASA Technical Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable to help minimize costs. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement or to specify proposed tailoring. The choice of having no applicability must be explained and justified in the Comments section.

D.2 REQUIREMENT COMPLIANCE MATRIX

Table D.2-1—Requirement Compliance Matrix

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
3.2	Human-Centered Task Analysis	[V2 3006]	Each human spaceflight program or project shall perform a human-centered task analysis to support systems and operations design.		
3.3	Human Error Analysis	[V2 3102]	Each human spaceflight program or project shall perform a task-based human error analysis (HEA) to support systems and operations design.		
3.4	Iterative Developmental Testing	[V2 3101]	Each human spaceflight program or project shall perform iterative human-in-the-loop (HITL) testing throughout the design and development cycle.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
4.1.1	Functional Anthropometric Accommodation	[V2 4102]	The system shall ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix E, Physical Characteristics and Capabilities, Sections E.2 and E.3.		
4.1.2	Body Mass, Volume, and Surface Area Data	[V2 4103]	The system shall accommodate the body characteristic data for mass, volume, and surface area as defined in Appendix E, Physical Characteristics and Capabilities, Sections E.4, E.5, and E.6.		
4.1.3.1	Crew Operational Loads	[V2 4104]	The system shall be operable by crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, with the lowest anticipated strength as defined in E, Physical Characteristics and Capabilities, Section E.7.		
4.1.3.2	Withstand Crew Loads	[V2 4105]	The system shall withstand forces imparted by the crew during all phases of flight, including but not limited to prelaunch, ascent, orbit, entry, and postlanding, as defined in Appendix E, Physical Characteristics and Capabilities, Section E.7 without sustaining damage.		
4.2	Muscle Effects	[V2 4013]	The effects of muscle endurance and fatigue shall be factored into system design.		
4.3	Aerobic Capacity	[V2 4015]	The system shall be operable by crewmembers with the aerobic capacity as defined in NASA-STD-3001, Volume 1.		
5.1.1	Operability	[V2 10003]	The system shall provide crew interfaces that enable tasks to be performed successfully within the appropriate time limit and degree of accuracy.		
5.1.2	Usability	[V2 10001]	The system shall provide crew interfaces that result in a NASA Modified System Usability Scale (NMSUS) score of 85 or higher.		
5.1.3	Design-Induced Error	[V2 10002]	The system shall provide crew interfaces that do not exceed the maximum observed error rates listed in Table 5.1-1—Maximum Observed Design-Induced Error Rates.		
5.1.4	Cognitive Workload	[V2 5007]	The system shall provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for tasks performed under degraded system conditions.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
5.1.5	Physical Workload	[V2 10200]	The system shall provide crew interfaces that result in a Borg-CR10 rating of perceived exertion (RPE) of 4 (somewhat strong) or less.		
5.1.6	Situation Awareness	[V2 5006]	Systems shall provide the Situation Awareness (SA) necessary for efficient and effective task performance and provide the means to recover SA, if lost, for anticipated levels of crewmember capability and anticipated levels of task demands.		
5.1.7	Legibility	[V2 5051]	The system shall provide crew interfaces that are legible under expected operating conditions.		
5.1.8	Controllability and Maneuverability During Manual Control (Handling Qualities – Level 1)	[V2 10004]	The spacecraft shall exhibit Level 1 handling qualities (Handling Qualities Rating (HQR) 1, 2 and 3), as defined by the Cooper-Harper Rating Scale, during manual control of the spacecraft's flight path and attitude when manual control is the primary control mode or automated control is non-operational.		
5.1.9	Controllability and Maneuverability During Manual Control with Deficiencies (Handling Qualities – Level 2)	[V2 5052]	The system shall exhibit Level 2 (HQR 4-6) or better handling qualities during manual control in all other scenarios not specified in [V2 10004] Handling Qualities – Level 1.		
5.2.1	Controls for Human Error	[V2 5053]	The system shall control for human error according to the following precedence: a. Design the system to prevent human error in the operation and control of the system. b. Design the system to reduce the likelihood of human error and provide the capability for the human to detect and correct or recover from the error. c. Design the system to limit the negative effects of the error.		
5.2.2	Protect Against Unintended Operator Actions	[V2 10027]	The system shall protect against inadvertent activation of controls.		
5.2.3	Error Detection and Recovery	[V2 10028]	The system shall provide the capability to detect and recover from human error and inadvertent changes in system status.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.1	Trend Analysis of Environmental and Suit Data	[V2 6001]	The system shall provide environmental and suit monitoring data in formats compatible with performing temporal trend analyses.		
6.2.1.1	Inert Diluent Gas	[V2 6002]	Cabin atmospheric composition shall contain at least 30% diluent gas (assuming balance oxygen).		
6.2.1.2	O2 Partial Pressure Range for Crew Exposure	[V2 6003]	The system shall maintain inspired oxygen partial pressure (PIO2) in accordance with Table 6.2-1—Inspired Oxygen Partial Pressure Exposure Ranges.		
6.2.1.3	Nominal Vehicle/Habitat Carbon Dioxide Levels	[V2 6004]	The system shall limit the average one-hour CO2 partial pressure (ppCO2) in the habitable volume to no more than 3 mmHg.		
6.2.2.1	Total Pressure Tolerance Range for Indefinite Crew Exposure	[V2 6006]	The system shall maintain the pressure to which the crew is exposed to between 34.5 kPa < pressure ≤ 103 kPa (5 psia < pressure ≤ 15.0 psia) for indefinite human exposure without measurable impairments to health or performance.		
6.2.2.2	Rate of Pressure Change	[V2 6007]	For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure shall not exceed 13.5 psi/min.		
6.2.2.3	Barotrauma Prevention	[V2 6150]	During a commanded pressure change, the system shall pause within 1 psi of the pause command being issued by the unsuited or suited crewmember, with ability to increase or decrease pressure as needed after the pause.		
6.2.2.4	Decompression Sickness (DCS) Risk Identification	[V2 6008]	Each program shall define mission unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence: a. DCS ≤ 15% (includes Type I or isolated cutis marmorata). b. Grade IV venous gas emboli (VGE) ≤ 20%. c. Prevent Type II DCS.		
6.2.2.5	Decompression Sickness Treatment Capability	[V2 6009]	The system shall provide DCS treatment capability.		
6.2.3	Post Landing Relative Humidity (RH)	[V2 6011]	For nominal post landing operations, the system shall limit RH to the levels in Table 6.2-2—Average Relative Humidity Exposure Limits for Post Landing Operations.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.2.4.1	Crew Health Environmental Limits	[V2 6012]	The system shall maintain levels of cabin humidity and temperature within the boundaries of the Operating Limits as shown in Figure 6.2-2—Crew Health Environmental Limits, to protect for crew health during pressurized operations when crew occupies the cabin, excluding suited operations, ascent, entry, landing, and post landing.		
6.2.4.2	Crew Performance Environmental Zone	[V2 6013]	The system shall be capable of reaching atmospheric humidity and temperatures of nominally occupied habitable volumes within the zone provided in Figure 6.2-3—Crew Performance Environmental Zone, during all nominal operations, excluding suited operations, ascent, entry, landing, and post landing.		
6.2.4.3	Temperature Selectability	[V2 6151]	The system shall provide selectable set points for internal atmosphere temperature in step sizes no greater than 0.5°C increments with a setpoint error of +/- 1.5°C in the habitable volume.		
6.2.4.4	Temperature Adjustability	[V2 6152]	The system shall be capable of adjusting temperature in the habitable volume by at least 1°C/hr.		
6.2.4.5	Environmental Control During Exercise	[V2 7041]	The system environmental control shall accommodate the increased O_2 consumption and additional output of heat, CO_2, perspiration droplets, odor, and particulates generated by the crew in an exercise area.		
6.2.5	Atmospheric Control	[V2 6017]	The system shall allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO_2.		
6.2.6.1	Atmospheric Data Recording	[V2 6020]	For each isolatable, habitable compartment, the system shall automatically record pressure, humidity, temperature, ppO_2, and $ppCO_2$ data continuously.		
6.2.6.2	Atmospheric Data Displaying	[V2 6021]	The system shall display real-time values for pressure, humidity, temperature, ppO_2, and $ppCO_2$ data to the crew locally and remotely.		
6.2.7.1	Atmospheric Monitoring and Alerting Parameters	[V2 6022]	The system shall alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO_2, and $ppCO_2$ are outside safe limits.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.2.7.2	Trace Constituent Monitoring and Alerting	[V2 6023]	The system shall monitor trace volatile organic compounds (VOCs) in the cabin atmosphere and alert the crew locally and remotely when they are approaching defined limits.		
6.2.7.3	Combustion Monitoring and Alerting	[V2 6024]	The system shall monitor in real-time the toxic atmospheric components listed in Table 6.2-3—Recommended Combustion Product (CP) Monitoring Ranges, that would result from pre-combustion and combustion events in the ranges and with the accuracy and resolution specified in the table and alert the crew locally and remotely in sufficient time for them to take appropriate action.		
6.2.7.4	Contamination Monitoring and Alerting	[V2 6025]	The system shall monitor and display atmospheric compound levels that result from contamination events, e.g., toxic release, systems leaks, or externally originated, before, during, and after an event and alert the crew locally and remotely in sufficient time for them to take appropriate action.		
6.2.7.5	Celestial Dust Monitoring and Alerting	[V2 6153]	The vehicle shall monitor celestial dust and alert the crew locally and remotely when they are approaching defined limits.		
6.2.8.1	Nominal Vehicle/Habitat Atmospheric Ventilation	[V2 6107]	The system shall maintain a ventilation rate within the internal atmosphere that is sufficient to provide circulation that prevents CO_2 and thermal pockets from forming, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.		
6.2.8.2	Off-Nominal Vehicle/Habitat Atmospheric Ventilation	[V2 6108]	The system shall control for ppO_2, $ppCO_2$, and relative humidity during off-nominal operations, for example during temporary maintenance activities in areas not in the normal habitable volume.		
6.2.9.1	Atmosphere Contamination Limit	[V2 6050]	The system shall limit gaseous pollutant accumulation in the habitable atmosphere below individual chemical concentration limits specified in JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants (SMACs).		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.2.9.2	Particulate Matter	[V2 6052]	The system shall limit the habitable atmosphere particulate matter concentration for total dust to <3 mg/m3 with a crew generation rate of 1.33 mg/person-minute, and the respirable fraction of the total dust <2.5 µm (micrometer) in aerodynamic diameter to <1 mg/m3 with a crew generation rate of 0.006 mg/person-minute.		
6.2.9.3	Lunar Dust Contamination	[V2 6053]	The system shall limit the levels of lunar dust particles less than 10 µm in size in the habitable atmosphere below a time-weighted average of 0.3 mg/m3 during intermittent daily exposure periods that may persist up to 6 months in duration.		
6.2.9.4	Microbial Air Contamination	[V2 6059]	The system shall provide air in the habitable atmosphere that is microbiologically safe for human health and performance.		
6.3.1.1	Potable Water Quality	[V2 6026]	At the point of crew consumption or contact, the system shall provide aesthetically acceptable potable water that is chemically and microbiologically safe for human use, including drinking, food rehydration, personal hygiene, and medical needs.		
6.3.1.3	Water Contamination Control	[V2 6051]	The system shall prevent potable and hygiene water supply contamination from microbial, atmospheric (including dust), chemical, and non-potable water sources to ensure that potable and hygiene water are provided.		
6.3.1.4	Water Quality Monitoring	[V2 6046]	The system shall provide the capability to monitor water quality and notify the crew locally and remotely when parameters are approaching defined limits.		
6.3.2	Water Quantity	[V2 6109]	The system shall provide a minimum water quantity as specified in Table 6.3-1—Water Quantities and Temperatures, for the expected needs of each mission, which should be considered mutually independent.		
6.3.3	Water Temperature	[V2 6110]	The system shall provide the appropriate water temperature as specified in Table 6.3-1—Water Quantities and Temperatures, for the expected needs of each mission and task.		
6.3.4.1	Potable Water Dispensing Rate	[V2 6039]	Water shall be dispensed at a rate that is compatible with the food system.		
6.3.4.2	Potable Water Dispensing Increments	[V2 6040]	To prevent overflow, water shall be dispensable in specified increments that are compatible with the food preparation instructions and time demands of the allotted meal schedule.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.4.1.1	Toxic Hazard Level Three	[V2 6047]	The system shall use only chemicals that are Toxic Hazard Level Three or below, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, in the habitable volume of the spacecraft.		
6.4.1.2	Toxic Hazard Level Four	[V2 6048]	The system shall prevent Toxic Hazard Level Four chemicals, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, from entering the habitable volume of the spacecraft.		
6.4.1.3	Chemical Decomposition	[V2 6049]	The system shall use only chemicals that, if released into the habitable volume, do not decompose into hazardous compounds that would threaten health during any phase of operations.		
6.4.2.1	Biological Payloads	[V2 6060]	Biological payloads, as well as the associated operational procedures and supporting personal protective equipment, shall meet the criteria defined by the JSC Biosafety Review Board guidelines contained in JPR-1800.5, Biosafety Review Board Operations and Requirements.		
6.4.2.2	Environment Cross-Contamination	[V2 6061]	The system shall provide controls to prevent or minimize (as appropriate) biological cross-contamination between crew, payloads and vehicles to acceptable levels in accordance with the biosafety levels (BSL) defined in JPR-1800.5, as well between crew, payloads, vehicles and extraterrestrial planetary environments with the extent of application specific to individual planetary bodies and special locations thereon.		
6.4.3	Availability of Environmental Hazards Information	[V2 6062]	The system shall provide toxicological and environmental hazard information in formats accessible by the crew and ground personnel throughout the mission.		
6.4.4	Contamination Cleanup	[V2 6063]	The system shall provide a means to remove or isolate released chemical and biological contaminants and to return the environment to a safe condition.		
6.5.1	Sustained Translational Acceleration Limits	[V2 6064]	The system shall limit the magnitude, direction, and duration of crew exposure to sustained (> 0.5 seconds) translational acceleration by staying below the limits in Figures 6.5-(2-7) and Tables 6.5-(1-6) for seated and standing postures.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.5.2.1	Rotational Velocity	[V2 6065]	The system shall limit crew exposure to rotational velocities in yaw, pitch, and roll by staying below the limits specified in Figure 6.5-8—Rotational Velocity Limits and Table 6.5-7—Rotational Velocity Limits.		
6.5.2.2	Sustained Rotational Acceleration Due to Cross-Coupled Rotation	[V2 6066]	The system shall prevent the crew exposure to sustained (>0.5 second) rotational accelerations caused by cross-coupled rotations greater than 2 rad/s2.		
6.5.2.3	Transient Rotational Acceleration	[V2 6067]	The system shall limit transient (≤0.5 seconds) rotational accelerations in yaw, pitch, or roll as specified in Table 6.5-8—Head CG Rotational Acceleration Limits, to which the crew is exposed. The limits are appropriately scaled for each crewmember size from the 50th percentile male limits of 2,200 rad/s2 for nominal and 3,800 rad/s2 for off-nominal cases.		
6.5.3	Acceleration Injury Prevention	[V2 6069]	The system shall mitigate the risk of injury to crewmembers caused by accelerations during dynamic mission phases per Table 6.5-9—Acceptable Injury Risk Due to Dynamic Loads.		
6.5.4	Injury Risk Criterion	[V2 6070]	The system shall limit crew exposure to transient translational acceleration (≤0.5 seconds) by limiting the injury risk criterion (β/beta) to no greater than 1.0 (Low) for seated or standing crew as defined by Dynamic Response (DR) limits in NASA/TM-20205008198 Table 2 "Updated Dynamic Response Limits for Standing", while crew are restrained as required in NASA/TM-2013-217380REV1 for seated crew, or NASA/TM – 20205008198 for standing crew.		
6.5.5	Dynamic Mission Phases Monitoring and Analysis	[V2 6111]	The system shall collect vehicle and crewmember acceleration parameters, specific kinematic responses, and associated metadata, during all dynamic mission phases and suited operations (defined as ascent, abort, entry, descent, landing, postlanding, and EVA operations) to correlate with any injuries incurred by crewmembers.		
6.5.6	Hang Time Limit	[V2 6112]	The system shall limit crew exposure to suspension trauma conditions to seven minutes or less.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.5.7	Crew Limits in Launch Orientation	[V2 6113]	The time in which crewmembers are on back with feet elevated in a launch configuration shall not exceed 3 hours and 15 minutes, excluding subsequent safing and egress time.		
6.5.8.1	Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits	[V2 6154]	The extraterrestrial surface transport vehicle (ESTV) system shall limit the magnitude of crewmember exposure to sustained (>0.5 seconds) translational acceleration by staying below the limits in Table 6.5-10—Extraterrestrial Surface Transport Vehicle Sustained Translation Acceleration Limits, which specify the ±Ax, ±Ay, and ±Az translational acceleration limits appropriate for specific restraint conditions.		
6.5.8.2	Extraterrestrial Surface Transport Vehicle Translation Jerk Limits	[V2 6155]	The extraterrestrial surface transport vehicle (ESTV) system shall limit the crewmember exposure to translational jerk to the limits given in Table 6.5-11—Extraterrestrial Surface Transport Vehicle Translation Jerk Limits, which specifies the ±Ax, ±Ay, and ±Az translational jerk limits appropriate for specific restraint conditions.		
6.5.8.3	Blunt Trauma Limits for Enabling Performance	[V2 6156]	The system shall limit the crewmember exposure to blunt trauma forces to the limits given in Figure 6.5-9—Performance Blunt Force Maximum Allowable Depth of Compression Limits (Seated or Standing Vehicle Occupants), which specifies the maximum allowable depth of compression across the occupant body (seated or standing), and below 18 pounds-force (lbf) across skeletal locations of concern outlined in Figure 6.5-10—Anthropometric Locations for Blunt Trauma Limits & Skeletal Locations of Concern: a. Manubrium of the Sternum – Point 1 b. Sternum (body) – Point 2 c. Clavicle – Points 10 & 11 d. Lateral aspect of the thorax – Points 22 & 23 e. Vertebral Column – Points 40, 41, & 42 f. Cervical Spine (C7) – Point 48 g. Scapula – Point 31 h. Spine – Point 39 i. Acromion Process – Point 49 j. Elbow (olecranon process) – Point 61		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.6.1.1	Launch, Entry, and Abort Noise Exposure Limits	[V2 6073]	During launch, entry, and abort operations, the noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, shall be limited such that the noise dose (D) is ≤100: where: N = the number of noise exposure events during the 24-hour period Cn = the actual duration of the exposure event in minutes Tn = the maximum noise exposure duration allowed, based on the specific sound level (Ln) of an exposure event in dBA, calculated using the following equation: T_n=480/2^((L_n-85)/3)		
6.6.1.2	Ceiling Limit for Launch and Entry	[V2 6074]	During launch and entry operations, the system shall limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 105 dBA.		
6.6.1.3	Ceiling Limit for Launch Abort	[V2 6075]	During launch abort operations, the system shall limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 115 dBA.		
6.6.1.4	Launch, Entry, and Abort Impulse Noise Limits	[V2 6076]	During launch, entry, and abort operations, impulse noise measured at the crewmember's ear location shall be limited to less than 140 dB peak SPL.		
6.6.1.5	Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort	[V2 6077]	For off-nominal operations, broadcast communications, pressurization valve noise, and maintenance activities, the A-weighted sound level (excluding impulse noise and alarm signals) shall be less than 85 dBA (using fast exponential-time-averaging), regardless of the measured time interval; except in the case of pressurization valve noise, the noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.6.1.6	24-Hour Noise Exposure Limits	[V2 6115]	The noise exposure level (not including impulse noise) at the crewmember's head, calculated over any 24-hour period, except during launch, entry, and abort operations, shall be limited such that the noise dose (D) is ≤100: $D=100\sum_{n=1}^{N} C_n/T_n$ where: N = the number of noise exposure events during the 24-hour period Cn = the actual duration of the exposure event in minutes Tn = the maximum noise exposure duration allowed, based on the specific sound level (Ln) of an exposure event in dBA, calculated using the following equation: $T_n=480/2^{((L_n-75)/3)}$		
6.6.1.7	Continuous Noise Limits	[V2 6078]	In spacecraft work areas, where good voice communications and habitability are required, SPLs of continuous noise (not including impulse or intermittent noise sources) shall be limited to the values given by the Noise Criterion (NC)-50 curve in Figure 6.6-1—NC Curves, and Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa; hearing protection cannot be used to satisfy this requirement.		
6.6.1.8	Crew Sleep Continuous Noise Limits	[V2 6079]	For missions greater than 30 days, SPLs of continuous noise shall be limited to the values given by the NC-40 curve (see Figure 6.6-1—NC Curves, and Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa) in crew quarters and sleep areas. Hearing protection cannot be used to satisfy this requirement.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.6.1.9	Intermittent Noise Limits	[V2 6080]	For hardware items that operate for eight hours or less (i.e. intermittent noise), the maximum noise emissions (not including impulse noise), measured 0.6 m from the loudest hardware surface, shall be determined according to Table 6.6-4—Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for Any 24-hour Period (measured at 0.6 m distance from the source or closest distance to crew head, whichever is less). Hearing protection cannot be used to satisfy this requirement.		
6.6.1.10	Alarm Maximum Sound Level Limit	[V2 6081]	The maximum alarm signal A-weighted sound level shall be less than 95 dBA at the operating position of the intended receiver.		
6.6.1.11	Annoyance Noise Limits for Crew Sleep	[V2 6082]	With the exception of communications and alarms, the system shall limit impulse and intermittent noise levels at the crewmember's head location to 10 dB above background noise levels during crew sleep periods. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.12	Impulse Noise Limit	[V2 6083]	The system shall limit impulse noise measured at the crewmember's head location to less than 140 dB peak SPL during all mission phases except launch, entry, and abort. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.13	Narrow-Band Noise Limits	[V2 6084]	The maximum SPL of narrow-band noise components and tones shall be limited to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone.		
6.6.1.14	Infrasonic Sound Pressure Limits	[V2 6085]	Infrasonic SPLs, including frequencies from 1 to 20 Hz but not including impulse noise, shall be limited to less than 150 dB at the crewmember's head location. Hearing protection cannot be used to satisfy this requirement.		
6.6.1.15	Noise Limit for Personal Audio Devices	[V2 6106]	The system shall limit the maximum A-weighted sound level at the crewmember's ear created by a personal audio device to 115 dBA or less when converted to a diffuse field.		
6.6.2.1	Acoustic and Noise Monitoring	[V2 6087]	Broadband and frequency-dependent SPLs shall be monitored and quantified as needed for crew health and safety.		
6.6.2.2	Individual Noise Exposure Monitoring	[V2 6088]	Noise exposure levels shall be monitored and quantified for each crewmember as needed for crew health and safety.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.7.1.1	Vibration during Pre-Flight	[V2 6089]	The system shall limit vibration to the crew such that the frequency-weighted acceleration between 0.1 to 0.5 Hz in each of the X, Y, and Z axes is less than 0.05 g (0.5 m/s2) root mean square (RMS) for each 10-minute interval during prelaunch (when calculated in accordance with ISO 2631-1:1997(E), Mechanical Vibration and Shock - Evaluation of Human Exposure to Whole-Body Vibration - Part 1: General Requirements, Annex D, Equation D-1).		
6.7.1.2	Vibration Exposures during Dynamic Phases of Flight	[V2 6090]	The system shall limit vibration during dynamic phases of flight at interfaces that transmit vibration to the crew such that the vectorial sum of the X, Y, and Z accelerations between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), is less than or equal to the levels for the accumulated durations in Table 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight, and Figure 6.7-1—Frequency-Weighted Vibration Limits by Exposure Time during Dynamic Phases of Flight.		
6.7.1.3	Long-Duration Vibration Exposure Limits for Health during Non-Sleep Phases of Mission	[V2 6091]	The system shall limit vibration at interfaces that transmit vibration to the crew such that the accumulated dosage of the vectorial sum of the X, Y, and Z frequency-weighted accelerations, as computed according to ISO 2631-1:1997(E), does not exceed the minimum health guidance caution zone level defined in Figure 6.7-2—Long-Duration Vibration Dosage Limits for Health during Non-Sleep Phases of Mission..		
6.7.1.4	Vibration Exposure Limits during Sleep	[V2 6092]	The system shall limit vibration to the crew such that the acceleration between 1.0 and 80 Hz in each of the X, Y, and Z axes, weighted in accordance with ISO 20283-5, Mechanical Vibration—Measurement of Vibration on Ships; Part 5 - Guidelines for the Measurement, Evaluation and Reporting of Vibration with Regard to Habitability on Passenger and Merchant Ships, Annex A, is less than 0.01 g (0.1 m/s2) RMS for each two-minute interval during the crew sleep period.		
6.7.1.5	Vibration Limits for Performance	[V2 6093]	The system shall ensure the appropriate level of crew task performance (e.g., motor control accuracy and precision, vision/readability, speech clarity, attentional focus) during vibration by evaluating task performance under all expected (nominal and off-nominal) vibration levels.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.7.2	Hand Vibration	[V2 6094]	The system, including tools, equipment, and processes, shall limit vibration to the crewmembers' hands such that the accelerations, as computed according to ANSI/ASA S2.70-2006, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand, do not exceed the Daily Exposure Action Value defined by ANSI/ASA S2.70-2006, Annex A, Figure A.1.		
6.7.3	Extraterrestrial Surface Transport Vehicle Vibration Limits for Health and Performance	[V2 6160]	The extraterrestrial surface transport vehicle (ESTV) system shall limit crewmember exposure to vibration such that the vectorial sum of the X, Y, and Z accelerations between 0.5 and 80 Hz, calculated in 1-s intervals and weighted in accordance with ISO 2631-1:1997(E), is less than or equal to the levels given in Figure 6.7-3—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants) and Table 6.7-2—Extraterrestrial Surface Transport Vehicle Vibration Limits (Seated or Standing Vehicle Occupants), which specify the allowable accumulated duration (per 24-hour day) of vibration for both standing or seated crewmembers in all restraint conditions.		
6.8.1.1	Radiation Environments	[V2 6098]	The program shall specify the radiation environments to be used for design requirements and verification.		
6.8.1.2	Ionizing Radiation Protection Limit	[V2 6095]	The program shall set system design requirements and operational constraints to prevent crewmembers from exceeding career space permissible exposure limits (PELs) as set forth in Section 4.8 of NASA-STD-3001, Volume 1.		
6.8.1.3	Intravehicular Area Monitoring of Space Radiation Exposure	[V2 6161]	The program shall monitor the radiation exposure produced by galactic cosmic rays, solar energetic particles, trapped radiation, and neutrons in habitable volumes as referenced in Table 6.8-1—Space Radiation Monitoring Requirements Mission Location vs. Required Monitoring.		
6.8.1.4	Personal Monitoring of Space Radiation Exposure	[V2 6162]	The program shall monitor the radiation exposure produced by galactic cosmic rays, solar energetic particles, and trapped radiation received by individual crew members as referenced in Table 6.8-1—Space Radiation Monitoring Requirements Mission Location vs. Required Monitoring.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
6.8.1.5	Area Monitoring of Radiation Exposure from Nuclear Technologies	[V2 6163]	The program shall monitor the crew ionizing radiation exposure from nuclear technologies.		
6.8.1.6	Alerting of Elevated Exposure Rates	[V2 6164]	The radiation monitoring system shall alert the crew and operations teams when radiation exposure rates exceed predefined thresholds.		
6.8.1.7	External Space Weather Monitoring	[V2 6165]	The program shall monitor the in-situ extravehicular space weather environment including the external exposure rates, electron flux spectra, and proton flux spectra.		
6.8.2.1	RF Non-Ionizing Radiation Exposure Limits	[V2 6102]	The system shall maintain the crew exposure to RF electromagnetic fields to or below the limits stated in Table 6.8-2—Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields and shown graphically in Figure 6.8-1—RF Electromagnetic Field Exposure Limits.		
6.8.2.2	Laser Exposure Limits	[V2 6103]	The system shall maintain the crew ocular and dermal exposure to laser systems and the ocular exposure of the uncontrolled ground population to space lasers to or below the limits specified in ANSI Z136.1, 2014, American National Standard for Safe Use of Lasers, Table 5 (ocular) and Table 7 (dermal) without Personal Protective Equipment.		
6.8.2.3	Natural Sunlight Exposure Limits	[V2 6104]	The system shall maintain the crew exposure to natural sunlight for spectral radiance or irradiance (as applicable) within wavelengths between 180 nm and 3000 nm, as noted in Table 6.8-3—Natural Sunlight Exposure Limits for Different Damage Mechanisms.		
6.8.2.4	Artificial Light Exposure Limits	[V2 6117]	The system shall limit crew exposure from Visible, Infrared (IR), near-IR and Ultraviolet (UV) artificial light sources (180 nm to 3000 nm) at or below the threshold limit value (TLV) as calculated per ACGIH version 2022 or later.		
7.1.1.1	Food Quality	[V2 7001]	The food system shall maintain food safety and nutrition during all phases of the mission.		
7.1.1.2	Food Acceptability	[V2 7002]	The system shall provide food that is acceptable to the crew for the duration of the mission.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
7.1.1.3	Food Caloric Content	[V2 7003]	The system shall provide each crewmember with an average of 12,698 kJ (3,035 kcal) per day, else an average energy requirement value is determined using Table 7.1-1—EER Equations and applying an activity factor appropriate to the mission gravity and planned level of physical activity.		
7.1.1.4	EVA Food Caloric Content	[V2 7004]	For crewmembers performing EVA operations, the food system shall provide an additional 837 kJ (200 kcal) per EVA hour above nominal metabolic intake as defined by [V2 7003] Food Caloric Content, of this NASA Technical Standard.		
7.1.1.5	Food Nutrient Composition	[V2 7100]	The system shall provide a food system with a diet including the nutrient composition that is indicated in the Dietary Reference Intake (DRI) values as recommended by the National Institutes of Health, with the exception of those adjusted for spaceflight as noted in Table 7.1-2—Nutrient Guidelines for Spaceflight.		
7.1.1.6	Food and Impacts to Environmental Systems	[V2 7110]	Food items and packaging shall be evaluated for impacts on vehicle systems.		
7.1.2.1	Food Safety	[V2 7111]	The program shall maintain flight food safety throughout product life cycle.		
7.1.2.2	Food Production Facility	[V2 7112]	The facility where food is prepared, processed, packaged, stowed, and stored shall comply with applicable laws and regulations, or FDA equivalent, as well as industry Good Manufacturing Practice standards.		
7.1.2.3	Food and Production Area Microorganism Levels	[V2 7007]	Microorganism levels in the food and production area shall not exceed those specified in Table 7.1-3—Food Microorganism Levels.		
7.1.2.4	Food Contamination Control	[V2 7010]	The food storage, preparation, and consumption areas within the vehicle shall be designed and located to protect against cross-contamination between food and the environment.		
7.1.2.5	Food System Cleaning and Sanitizing	[V2 7015]	The system shall provide methods for cleaning and sanitizing food facilities, equipment, and work areas.		
7.1.2.6	Food Spill Control	[V2 7014]	The system shall provide the ability to contain and remove food particles and spills.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
7.1.3.1	Food Preparation	[V2 7008]	The system shall provide the capability for preparation, consumption, and stowage of food.		
7.1.3.2	Food Preparation and Cleanup	[V2 7009]	The food system shall allow the crew to unstow supplies, prepare meals, and clean up for all crewmembers within the allotted meal schedule.		
7.1.3.3	Food and Beverage Heating	[V2 7011]	The system shall provide the capability to heat food and beverages to a temperature appropriate for the given item.		
7.1.3.4	Dining Accommodations	[V2 7012]	The system shall provide adequate volume and accommodations for crewmembers to dine together.		
7.2.1	Personal Hygiene Capability	[V2 7016]	Personal hygiene items shall be provided for each crewmember, along with corresponding system capabilities for oral hygiene, personal grooming, and body cleansing.		
7.2.2	Body Cleansing Privacy	[V2 7017]	The system shall provide for privacy during personal hygiene activities.		
7.2.3	Hygiene Maintainability	[V2 7019]	The system shall provide an environmentally compatible sanitization method for personal hygiene facilities and equipment.		
7.3.1.1	Body Waste Management Capability	[V2 7020]	The system shall provide the capability for collection, containment, and disposal of body waste for both males and females.		
7.3.1.2	Body Waste Management System Location	[V2 7021]	The body waste management system shall be isolated from the food preparation and consumption areas for aesthetic and hygienic purposes.		
7.3.1.3	Body Waste Management Privacy	[V2 7022]	The system shall provide privacy during use of the body waste management system.		
7.3.1.4	Body Waste Management Provision	[V2 7023]	Body waste management supplies shall be provided for each crewmember and be located within reach of crewmembers using the body waste management system.		
7.3.1.5	Body Waste Accommodation	[V2 7024]	The body waste management system shall allow a crewmember to urinate and defecate simultaneously without completely removing lower clothing.		
7.3.1.6	Body Waste Containment	[V2 7025]	The system shall prevent the release of body waste from the body waste management system.		
7.3.1.7	Body Waste Odor	[V2 7026]	The system shall provide odor control for the body waste management system.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
7.3.1.8	Body Waste Trash Receptacle Accessibility	[V2 7027]	Body waste management trash collection shall be accessible to and within reach of crewmembers using the body waste management system.		
7.3.1.9	Body Waste Management Maintenance	[V2 7029]	All body waste management facilities and equipment shall be capable of being cleaned, sanitized, and maintained.		
7.3.1.10	Body Waste Isolation	[V2 7101]	For missions greater than 30 days, the system shall provide separate dedicated volumes for body waste management and personal hygiene.		
7.3.2.1	Body Waste Quantities	[V2 7102]	The human body waste management system shall be capable of collecting and containing the various human body waste as specified in Table 7.3-1—Body Waste Quantities, for the expected needs of each mission and task.		
7.3.2.2	Fecal and Urine Elimination Concurrence	[V2 7085]	The body waste management system shall be capable of collecting and containing all waste during simultaneous defecation and urination.		
7.3.2.3	Urine per Crewmember	[V2 7035]	The human body waste management system shall be capable of collecting and containing urine for either processing or disposal of an average total urine output volume of $V_u = 3 + 2.5t$ liters per crewmember, where t is the mission length in days.		
7.4.1	Physiological Countermeasures Capability	[V2 7038]	The system shall provide countermeasures to meet crew bone, muscle, sensorimotor, thermoregulation, and aerobic/cardiovascular requirements defined in NASA-STD-3001, Volume 1.		
7.4.2	Physiological Countermeasure Operations	[V2 7040]	The physiological countermeasure system design shall allow the crew to unstow supplies, perform operations, and stow items within the allotted countermeasure schedule.		
7.4.3	Orthostatic Intolerance Countermeasures	[V2 7042]	The system shall provide countermeasures to mitigate the effects of orthostatic intolerance when transitioning from weightlessness to gravity environments and during Az (head-to-foot) vehicle accelerations defined in the sustained acceleration limits.		
7.5.1	Medical Capability	[V2 7043]	A medical system shall be provided to the crew to meet the medical requirements of NASA-STD-3001, Volume 1.		
7.5.2	Medical Equipment Usability	[V2 7045]	Medical equipment shall be usable by non-physician crewmembers in the event that a physician crewmember is not present or is the one who requires medical treatment.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
7.5.3	Medical Treatment Restraints	[V2 7046]	The medical system shall provide equipment to position and restrain a patient, care provider, and supplies during treatment.		
7.5.4	Medical Treatment, Personal Supplies and Impacts to Environmental Systems	[V2 7115]	Medical treatment, including pharmaceuticals, non-pharmaceutical crew care items, and related supplies, shall be evaluated for impacts on vehicle systems.		
7.6.1.1	Stowage Provisions	[V2 7050]	The system shall provide for the stowage of hardware and supplies, to include location, restraint, and protection for these items.		
7.6.1.2	Personal Stowage	[V2 7051]	The system shall provide a stowage location for personal items and clothing.		
7.6.1.3	Stowage Location	[V2 7052]	All relocatable items, e.g., food, EVA suits, and spare parts, shall have a dedicated stowage location.		
7.6.1.4	Stowage Interference	[V2 7053]	The system shall provide defined stowage locations that do not interfere with crew operations.		
7.6.1.5	Stowage Restraints	[V2 7054]	The system shall provide the capability to restrain hardware, supplies, and crew personal items that are removed or deployed for use as defined by crew task analysis.		
7.6.2.1	Priority of Stowage Accessibility	[V2 7055]	Stowage items shall be accessible in accordance with their use, with the easiest accessibility for mission-critical and most frequently used items.		
7.6.2.2	Stowage Operation without Tools	[V2 7056]	Stowage containers and restraints shall be operable without the use of tools.		
7.6.2.3	Stowage Access while Suited	[V2 7057]	The stowage system shall be accessible by a suited crewmember.		
7.6.3	Identification System	[V2 7058]	The stowage identification system shall be compatible with the inventory management system.		
7.7.1	Inventory Tracking	[V2 7059]	The system shall provide an inventory management system to track the locations and quantities of items (including hazardous trash) throughout the mission.		
7.7.2	Inventory Operations	[V2 7060]	The system shall be designed to allow inventory management functions to be completed within the allotted schedule.		
7.7.3	Nomenclature Consistency	[V2 7061]	The nomenclature used to refer to the items tracked by the inventory management system shall be consistent with procedures and labels.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
7.7.4	Unique Item Identification	[V2 7062]	Items that need to be uniquely identified shall have a unique name.		
7.7.5	Interchangeable Item Nomenclature	[V2 7063]	Items within the inventory management system that are identical and interchangeable shall have identical nomenclature.		
7.8.1.1	Trash Accommodation	[V2 7064]	The system shall provide a trash management system to contain, mitigate odors, prevent release, and dispose of all expected trash.		
7.8.1.2	Trash Volume Allocation	[V2 7065]	Trash stowage volumes shall be allocated for each mission.		
7.8.1.3	Trash Stowage Interference	[V2 7066]	The system shall provide defined trash stowage that does not interfere with crew operations.		
7.8.2	Labeling of Hazardous Waste	[V2 7069]	The hazard response level (HRL) of all liquids, particles, gases and gels shall be labeled on the outermost containment barrier in location(s) visible to crew.		
7.9.1	Sleep Accommodation	[V2 7070]	The system shall provide volume, restraint, accommodations, environmental control (e.g., vibration, lighting, noise, and temperature), and degree of privacy for sleep for each crewmember, to support overall crew health and performance.		
7.9.2	Behavioral Health and Privacy	[V2 7071]	For long duration missions (>30 days), individual privacy facilities shall be provided.		
7.9.3	Partial-g Sleeping	[V2 7073]	The system shall provide for horizontal sleep surface areas for partial-g and 1-g environments.		
7.10.1	Clothing Quantity	[V2 7074]	Clean, durable clothing shall be provided in quantities sufficient to meet crew needs.		
7.10.2	Clothing Exclusive Use	[V2 7075]	Clothing shall be provided for each individual crewmember’s exclusive use.		
7.10.3	Clothing Safety and Comfort	[V2 7076]	Clothing shall be comfortable in fit and composition, for the environment, e.g., temperature and humidity, in which it will be worn.		
7.11.1	Accessibility for Cleaning	[V2 7079]	The system shall provide sufficient volume to access areas that need to be cleaned and perform housekeeping duties.		
7.11.2	Particulate Control	[V2 7080]	The system shall be designed for access, inspection, and removal of particulates that can be present before launch or that can result from mission operations.		
7.11.3	Microbial Surface Contamination	[V2 7081]	The system shall provide surfaces that are microbiologically safe for human contact.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
7.11.4	Surface Material Cleaning	[V2 7082]	The system shall contain surface materials that can be easily cleaned and sanitized using planned cleaning methods.		
7.11.5	Cleaning Materials	[V2 7083]	The system shall provide cleaning materials that are effective, safe for human use, and compatible with system water reclamation, air revitalization, waste management systems, spacesuits and other spacecraft materials.		
7.11.6	Condensation Limitation	[V2 6058]	The system shall prevent condensation persistence on surfaces within the vehicle.		
7.11.7	Dust Removal	[V2 7113]	Any item exposed to extraterrestrial surface dust brought into the pressurized environments shall withstand the planned cleaning methods without damage.		
7.12	Recreational Capabilities	[V2 7084]	The system shall provide individual and team-oriented recreational capabilities for the crew to maintain behavioral and psychological health.		
8.1.1	Volume Allocation	[V2 8001]	The system shall provide the defined habitable volume and layout to physically accommodate crew operations and living.		
8.1.2	Functional Arrangement	[V2 8005]	Habitability functions shall be located based on the use of common equipment, interferences, and the sequence and compatibility of operations.		
8.1.3	Interference	[V2 8006]	The system shall separate functional areas whose functions would detrimentally interfere with each other.		
8.2.1	Spatial and Interface Orientation	[V2 8007]	The system shall have consistent spatial and interface orientations relative to a defined vertical orientation.		
8.2.2	Location Identifiers	[V2 8010]	A standard location coding system shall be provided to uniquely identify each predefined location within the system.		
8.2.3	Location Aids	[V2 8011]	The system shall provide aids to assist crewmembers in locating items or places within the system and orienting themselves in relation to those items or places.		
8.3.1	Intravehicular Translation Paths	[V2 8013]	The system shall provide intravehicular activity (IVA) translation paths that allow for safe and unencumbered movement of suited and unsuited crew and equipment.		
8.3.2	Emergency Escape Paths	[V2 8014]	The system shall provide unimpeded and visible emergency escape routes commensurate with the hazard analyses and response concepts.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
8.3.3	Assisted Ingress and Egress Translation Path	[V2 8020]	The system shall provide translation paths that accommodate the ingress and egress of a crewmember assisted by another crewmember.		
8.3.4	EVA Translation Path Hazard Avoidance	[V2 11005]	EVA translation paths shall be free from hazards.		
8.4.1.1	Hatches and Door Operation without Tools	[V2 8022]	Hatches and doors shall be operable on either side by a single crewmember without the use of tools in expected gravity conditions, orientations, suit configurations, and operational configurations.		
8.4.1.2	Unlatching Hatches	[V2 8023]	Hatches shall require two distinct and sequential operations to unlatch.		
8.4.1.3	Hatch and Door Operating Times	[V2 8024]	For nominal operations, hatches and doors shall be operable by a single crewmember in no more than 60 seconds, from both sides of the hatch.		
8.4.1.4	Hatch and Door Operating Force	[V2 8025]	The forces required to operate each crew interface for the hatches and doors shall be within the crewmember strength defined by requirement [V2 4104] Crew Operational Loads for the worst-case pressure differential and anticipated encumbering equipment and clothing.		
8.4.2.1	Hatchway Size and Shape	[V2 8027]	Hatchways and doorways shall be sized and shaped to accommodate all planned translations, including unrestricted passage of a suited crewmember and crewmembers carrying cargo or equipment.		
8.4.2.2	Pressure Equalization across the Hatch	[V2 8028]	Each side of each hatch shall have manual pressure equalization capability with its opposite side, achievable from that side of the pressure hatch by a suited or unsuited crewmember.		
8.4.2.3	Visibility across the Hatch	[V2 8029]	The system shall provide a window for direct, non-electronic visual observation of the environment on the opposite side of the hatch.		
8.4.3.1	Hatch, Hatch Cover and Door Interference	[V2 8030]	When opened, hatches, hatch covers and doors shall allow for unrestricted flow of traffic.		
8.4.3.2	Hatch Closure and Latching Status Indication	[V2 8031]	Pressure hatches shall indicate closure and latching status on both sides of the hatch.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
8.4.3.3	Hatch Pressure Indication	[V2 8032]	Pressure hatches shall indicate, viewable from both sides of the hatch, pressure differential across the hatch.		
8.4.4	No Drag-Throughs	[V2 8101]	Hatchways shall be clear of drag-throughs.		
8.5.1	Restraints for Crew Tasks	[V2 8033]	The system shall provide restraints for expected crew operations.		
8.5.2	Restraint and Mobility Aid Standardization	[V2 8038]	Restraints and mobility aids shall be standardized, clearly distinguishable, and located to aid crewmembers in starting or stopping movement, changing direction or speed, or translating equipment.		
8.5.3	Mobility Aid for Assisted Ingress and Egress	[V2 8040]	Mobility aids shall be provided for the assisted ingress and egress of suited or unsuited crewmembers.		
8.5.4	Unassisted Ingress, Egress, and Escape Mobility Aids	[V2 8041]	Mobility aids shall be provided for ingress, egress, and escape of crewmembers without assistance from other crew or ground personnel.		
8.5.5	Mobility Aids Provision	[V2 8042]	Mobility aids shall be provided to support all expected suited and unsuited tasks.		
8.6.1	Window Provisioning	[V2 8043]	The system shall provide windows with unobstructed fields of view for expected crew operations.		
8.6.2	Window Optical Properties	[V2 8045]	System windows shall have optical properties commensurate with crew task needs.		
8.6.3	Window Light Blocking	[V2 8049]	Each system window shall provide a means to prevent external light from entering the crew compartment, such that the interior light level can be reduced to 2.0 lux at 0.5 m (20 in) from each window.		
8.6.4	Window Accessory Replacement/Operation without Tools	[V2 8050]	System window accessories designed for routine use shall be operable by one crewmember and be removable or replaceable without the use of tools.		
8.7.1	Illumination Levels	[V2 8051]	For interior architectures and exterior operations that do not include the presence of orbital sunlight, the system shall provide illumination levels to support the range of expected crew tasks, at minimum, per Table 8.7-1—Surface Illuminance Levels, that accommodate both human observers and remote camera systems.		
8.7.2	Environmental Lighting Attenuation	[V2 8103]	The integrated system architecture shall provide countermeasures to attenuate environmental lighting and complement existing active lighting architecture.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
8.7.3	Task-Specific Exterior Lighting for Operational Areas Partially or Fully Lit by Sunlight	[V2 8104]	For operational areas that include shadowed areas and areas illuminated by the Sun and celestial bodies, the system shall provide passive and/or active solutions that reduce the contrast within shadowed areas of worksites/tasks to within 2 orders of magnitude of the predicted maximum surface luminance of objects, that accommodate both human observers and remote camera systems.		
8.7.4	Navigation and Wayfinding (Exterior)	[V2 8105]	The system shall provide luminous powered and passive indicators that assist with proximity, navigation, and object recognition for validation of targets critical to the surface operation.		
8.7.5	Emergency Lighting	[V2 8053]	The system shall provide emergency lighting (interior and exterior) to maintain visibility in the event of a general power failure.		
8.7.6	White Lighting Chromaticity	[V2 8059]	Interior and exterior lighting intended for operational environments requiring human/camera color vision shall have a chromaticity that falls within the chromaticity gamut for white light for the Correlated Color Temperature (CCT) range of 2700 K to 6500 K as defined by ANSI C78-377, Electric Lamps—Specifications for the Chromaticity of Solid-State Lighting Products.		
8.7.7	White Lighting Color Accuracy	[V2 8060]	Interior and exterior lighting intended for human operational environments requiring photopic vision accuracy shall have a score of 90 ±10 on a color fidelity metric that is appropriate for the utilized lighting technology, as designated by the Color Fidelity Metric (Rf) defined by IES TM-30, Method for Evaluating Light Sources Color Rendition methodology.		
8.7.8	Physiological Effects of Light (Circadian Entrainment)	[V2 8055]	The system shall provide the levels of light to support the physiological effects of light in accordance with Table 8.7-2—Physiological Lighting Specifications.		
8.7.9	Lighting Controls	[V2 8056]	Lighting systems shall have on-off controls.		
8.7.10	Lighting Adjustability	[V2 8057]	Interior and exterior lights shall be adjustable (dimmable).		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
8.7.11	Glare Prevention	[V2 8058]	The integrated system architecture including surrounding surfaces, support equipment, visualization tools, and supporting lighting systems shall work in conjunction to minimize visibility and eye-safety impacts from direct and indirect glare.		
8.7.12	Extraterrestrial Surface Transport Vehicle (ESTV) Dashboard and Control Lighting	[V2 8106]	The system shall provide active lighting and attenuation of solar light for manual controls (e.g., unpressurized surface transport vehicle joystick controls, switches and dashboard) and display screens to be visible in all potential natural light levels, including complete darkness.		
9.1.1	Crew Interface Commonality	[V2 9001]	Hardware and equipment performing similar functions shall have commonality of crew interfaces.		
9.1.2	Differentiation	[V2 9002]	Hardware and equipment that have the same or similar form but different functions shall be readily identifiable, distinguishable, and not be physically interchangeable.		
9.1.3	Routine Operation	[V2 9003]	Worksites shall be designed to provide rapid access to needed tools and equipment for routine/nominal operations.		
9.2.1	Training Minimization	[V2 9004]	Hardware and equipment with which crew interact shall minimize the time required for training.		
9.2.2	In-Mission Training	[V2 9110]	In-mission training/refreshers, including using tools and test equipment required for maintenance, shall be provided to ensure crew proficiency in performing maintenance activities.		
9.3.1.1	Design for Crew Safety	[V2 9101]	The system shall be designed to minimize physical hazards to the crew.		
9.3.1.2	Mechanical Hazard	[V2 9005]	Systems, hardware, and equipment shall protect the crew from moving parts that may cause injury to the crew.		
9.3.1.3	Entrapment	[V2 9006]	Systems, hardware, and equipment shall protect the crew from entrapment (tangles, snags, catches, etc.).		
9.3.1.4	Potential Energy	[V2 9007]	Hardware and equipment shall not release stored potential energy in a manner that causes injury to the crew.		
9.3.1.5	Protection from Projectiles and Structural Collapse	[V2 9008]	Hardware mounting and habitat enclosures shall be configured such that the crew is protected from projectiles and structural collapse in the event of sudden changes in acceleration or collisions.		
9.3.1.6	Sharp Corners and Edges – Fixed	[V2 9009]	Corners and edges of fixed and handheld equipment to which the bare skin of the crew could be exposed shall be rounded as specified in Table 9.3-1—Corners and Edges.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
9.3.1.7	Protection from Functionally Sharp Items	[V2 9010]	Functionally sharp items shall be prevented from causing injury to the crew or damage to equipment when not in use.		
9.3.1.8	Sharp Corners and Edges - Loose	[V2 9011]	Corners and edges of loose equipment to which the crew could be exposed shall be rounded to radii no less than those given in Table 9.3-2—Loose Equipment Corners and Edges.		
9.3.1.9	Burrs	[V2 9012]	Exposed surfaces shall be free of burrs.		
9.3.1.10	Pinch Points	[V2 9013]	Pinch points shall be covered or otherwise prevented from causing injury to the crew.		
9.3.1.11	Equipment Handling	[V2 9016]	All items designed to be carried or removed and replaced shall have a means for grasping, handling, and carrying while wearing the most encumbering equipment and clothing anticipated.		
9.3.2.1	Skin/Tissue Damage Temperature Limits	[V2 9102]	Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to exceed the injury limits in Table 9.3-4—Skin Temperature Injury Limits.		
9.3.2.2	Pain/Non-Disabling Injury Skin Temperature Limits	[V2 9103]	Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to exceed the injury limits in Table 9.3-5—Range/Limits Pain/Non-Disabling Injury/Possibly Resulting in Illness.		
9.3.3.1	Power Interruption	[V2 9017]	The system shall provide the crew with capability to control the power to an electrical circuit.		
9.3.3.2	Energized Status	[V2 9018]	The system shall provide and display the de-energized status (interruption of electrical power) of a circuit to the crew and within their fields of regard.		
9.3.3.3	Nominal Physiological Electrical Current Limits	[V2 9019]	Under nominal situations (routine human contacts to conductive housing), the program shall limit electrical current through the crewmember to ≤ (less than or equal to) 0.4 mA for Direct Current (DC) and ≤ (less than or equal to) 0.2 mA peak for Alternating Current (AC).		
9.3.3.4.1	Catastrophic Physiological Electrical Current Limits for all Circumstances	[V2 9020]	The program shall limit the electrical current through the crewmember to ≤ (less than or equal to) 40mA for DC and ≤ (less than or equal to) 8 mA peak for AC to avoid catastrophic physiological effects to the crewmember.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
9.3.3.4.2	Catastrophic Physiological Electrical Current Limits for Startle Reaction	[V2 9021]	During critical operations where a startle reaction is possible, the program shall limit electrical current through the crewmember to ≤ (less than or equal to) 2 mA for DC and ≤ (less than or equal to) 0.5 mA for AC to avoid potentially catastrophic conditions.		
9.3.3.5	Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds	[V2 9022]	The program/project shall use the 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC 60479-1, Effects of current on human beings and livestock - Part 1: General Aspects, to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.		
9.3.3.6	Leakage Currents – Medical and Bioinstrumentation Equipment	[V2 9023]	For equipment such as bioinstrumentation and medical devices, that are specifically designed to contact the human body, electrical leakage currents caused by contact with exposed surfaces (including in worst-case fault scenarios) shall be kept below the levels specified in Table 9.3-11—Leakage Currents-Medical and Bioinstrumentation Equipment.		
9.3.4.1	Fluid/Gas Release	[V2 9024]	Hardware and equipment shall not release stored fluids or gases in a manner that causes injury to the crew.		
9.3.4.2	Fluid/Gas Isolation	[V2 9025]	The system shall provide for the isolation or shutoff of fluids in hardware and equipment.		
9.3.4.3	Fluid/Gas Containment	[V2 9026]	The system shall provide for containment and disposal of fluids that might be released during operation or maintenance.		
9.4.1	Equipment Protection	[V2 9027]	Systems, hardware, and equipment shall be protected from and be capable of withstanding forces imposed intentionally or unintentionally by the crew.		
9.4.2	Isolation of Crew from Spacecraft Equipment	[V2 9028]	Protective provisions, e.g., close-out panels, shall be provided to isolate and separate equipment from the crew within the habitable volume.		
9.5.1	Hardware and Equipment Mounting and Installation	[V2 9029]	System hardware and equipment shall be designed so that it cannot be mounted or installed improperly.		
9.5.2.1	Connector Spacing	[V2 9030]	The spacing between connectors shall permit mating and demating by crewmembers wearing expected clothing.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
9.5.2.2	Connector Actuation without Tools	[V2 9031]	Connectors shall be operable without tools for mating and demating while wearing the most encumbering equipment and clothing anticipated.		
9.5.2.3	Incorrect Mating, Demating Prevention	[V2 9032]	Cable, gas and fluid lines, and electrical umbilical connectors shall prevent potential mismating and damage associated with mating or demating tasks.		
9.5.2.4	Mating, Demating Hazards	[V2 9033]	The system shall not subject personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy, during mating or demating.		
9.6.1	Cable Management	[V2 9034]	The system shall manage cable, wire, and hose location, protection, routing, and retention to prevent physical interference with crew operations and safety.		
9.7.1.1	Maintenance Concept of Operations	[V2 9111]	For each maintenance-level item, the human spaceflight program shall define and document a maintenance operational concept considering the following factors, as a minimum, and updated throughout the design lifecycle: a. Mission work natural environment (e.g., dust, lighting, heating, atmosphere, gravity) as specified in program requirements for natural environments (e.g., SLS-SPEC-159 Cross Program Design Specification for Natural Environments (DSNE)). b. Tools, aids, and support equipment available to the maintainers in-situ. c. Skill-level of the maintainers (i.e., crewmembers). d. Access needed to equipment – considering mission-criticality, urgency of repair, anticipated frequency of servicing, and complexity of approach. e. Reliability- or performance-driven preventive maintenance schedule. f. Preventive and corrective maintenance plans. g. Total crew time and number of crew needed.		
9.7.1.2	Availability of Critical Systems	[V2 9112]	System repairs and/or replacements shall be designed to be completed within the time-to-effect margin.		
9.7.1.3	Damage Prevention	[V2 9113]	The system shall be designed to prevent damage during maintenance.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
9.7.1.4	In-Mission Maintenance	[V2 9114]	The program shall design all flight hardware and software to facilitate in-mission preventive and corrective maintenance and check-out.		
9.7.1.5	Design for Maintenance	[V2 9036]	The system shall provide the means necessary for the crew to safely and efficiently perform routine service, maintenance, and anticipated unscheduled maintenance activities while wearing the most encumbering equipment and clothing anticipated.		
9.7.1.6	Commercial Off-the-Shelf (COTS) Equipment Maintenance	[V2 9037]	Maintenance for commercial off-the-shelf equipment shall be suitable to the spaceflight environment.		
9.7.2.1	In-Mission Tool Set	[V2 9038]	The program shall establish a common set of in-mission tools and test equipment for spaceflight and surface systems.		
9.7.2.2	Maintenance Tools Usability	[V2 9115]	Tools and test equipment shall be usable by the full range of crew sizes and strengths wearing any personal protective equipment (PPE).		
9.7.2.3	Tool and Test Equipment Commonality	[V2 9116]	Systems and units of equipment shall be designed so that maintenance can be accomplished with the set of in-mission tools and test equipment.		
9.7.2.4	Tool Clearance	[V2 9050]	The system shall provide tool clearances for tool installation and actuation for all tool interfaces during in-mission maintenance.		
9.7.3.1	Maintenance Time	[V2 9039]	Planned maintenance for systems and associated hardware and equipment shall be capable of being performed within the allotted crew schedule while wearing the most encumbering equipment and clothing anticipated.		
9.7.3.2	Captive Fasteners	[V2 9042]	Fasteners used by the crew during maintenance shall be captive.		
9.7.3.3	Minimum Number of Fasteners - Item	[V2 9043]	For items that may be serviceable by the crew, the number of fasteners used shall be the minimum required to meet structural engineering integrity requirements.		
9.7.3.4	Minimum Variety of Fasteners - System	[V2 9044]	The system shall be serviceable with a common set of fasteners that meet structural integrity requirements.		
9.7.4.1	Access Using Available Tools	[V2 9117]	Systems and units of equipment that require maintenance shall be accessible and openable during the mission using the on-board tool set.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
9.7.4.2	Maintenance Item Location	[V2 9045]	The system shall ensure maintenance access to the items prioritized [V2 9111] Maintenance Concept of Operations, so that the maintenance task does not require the removal or disabling of other systems or components (excluding access panels).		
9.7.4.3	Check and Service Point Accessibility	[V2 9046]	Check points and service points for systems, hardware, and equipment shall be directly accessible while wearing the most encumbering equipment and clothing anticipated.		
9.7.4.4	Maintenance Accommodation	[V2 9047]	Physical work access envelopes shall accommodate the crew, required tools, and any protective equipment needed to perform maintenance.		
9.7.4.5	Visual Access for Maintenance	[V2 9048]	Maintenance tasks that require visual feedback shall be directly visible during task performance while wearing the most encumbering equipment and clothing anticipated.		
9.7.5.1	Component Identification	[V2 9118]	Flight systems shall include information and labeling that enables the crew to correctly locate, handle, and identify the systems components.		
9.7.5.2	Cable Identification	[V2 9035]	All maintainable cables, wires, and hoses shall be uniquely and consistently identified at the maintenance point.		
9.7.5.3	Visual Aids for Maintenance	[V2 9119]	For maintenance activities, visual aids shall be provided with appropriate scale, orientation, and context to enable crew to locate and identify components and execute the task.		
9.7.6.1	Fault Detection	[V2 9051]	Unit of equipment undergoing maintenance shall provide rapid and positive fault detection and isolation of defective items.		
9.7.6.2	Failure Notification	[V2 9052]	The system shall alert the crew when critical equipment has failed or is not operating within tolerance limits.		
9.7.7.1	Condition Monitoring	[V2 9120]	The system shall be designed to provide condition-monitoring data to an information system that can be accessed by the crew, to maintenance data systems or mission control. (See also 10.2.1 System Health and Status.)		
9.7.7.2	Maintenance Management Information	[V2 9121]	For each maintenance-level item, as a minimum, the following data shall be captured and made/available to the crew: a. Procedures b. Visual aids c. Functional state data (e.g., power, temperature, pressure, standby)		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			d. Active indication of critical procedure step completion e. Active indication of restored functionality f. Replacement unit maintenance history g. Procedure execution records		
9.7.7.3	Fault Management Information	[V2 9122]	For maintenance-level items experiencing off-nominal performance, the following data shall be made available to the crew in real-time: a. Live diagnostic sensor data b. Troubleshooting steps and decision trees c. Description of possible faults and locations d. Description of test points and normal reading ranges e. Test result interpretations and corrective action recommendations		
9.7.8.1	Maintenance Activities	[V2 9123]	Maintenance activities shall be designed to the skillset common to all crewmembers at the time of maintenance.		
9.7.8.2	Maintenance Decision Aids	[V2 9124]	For corrective maintenance activities, decision aids shall be provided to support diagnosis, troubleshooting, and procedure execution at the expertise-level common to all crewmembers.		
9.7.8.3	Verification of Repair	[V2 9125]	Preventive and corrective maintenance shall include means for verification of successful completion.		
9.7.9.1	Contamination Prevention	[V2 9126]	For planetary surface missions, maintenance tasks shall be designed to prevent environmental contamination (e.g., dust) of maintenance items and EVA systems.		
9.7.9.2	Extreme Environment (EE)	[V2 9127]	Equipment, including tools and instruments, that are maintained on the planetary surface shall be designed to meet all performance requirements specified in NASA-STD-5017A Design and Development Requirements for Mechanisms during and after exposure to the expected natural environmental conditions specified in the SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE).		
9.7.9.3	Dust Tolerance	[V2 9128]	Tool and equipment functionality shall not reduce below minimum performance specifications due to dust exposure when designs cannot prevent its intrusion.		
9.8.1.1.1	Protective Equipment	[V2 9053]	Protective equipment shall be provided to protect the crew from expected hazards.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
9.8.1.1.2	Protective Equipment Use	[V2 9054]	Protective equipment shall not interfere with the crew's ability to conduct the nominal or contingency operations that the crew is expected to perform while employing the protective equipment, including communication among crewmembers and with ground personnel.		
9.8.1.1.3	Equipment Automation of Rescue Aids	[V2 9055]	Automation of protective equipment rescue aids shall be provided when the crew cannot perform assigned life-saving tasks.		
9.8.1.2.1	Use of Hearing Protection	[V2 9056]	The system shall meet SPL limits of section 6.6, Acoustics, in this NASA Technical Standard, except where otherwise specified in this NASA Technical Standard, without requiring the use of personal hearing protection.		
9.8.1.2.2	Hearing Protection Provision	[V2 9057]	Appropriate personal hearing protection shall be provided to the crew during all mission phases for contingency or personal preference.		
9.8.1.2.3	Hearing Protection Interference	[V2 9058]	The system shall be designed so that hearing protection does not inhibit voice communication, monitoring of systems, and detection of alerts.		
9.8.2.1	Fire Detecting, Warning, and Extinguishing	[V2 9059]	The vehicle shall have a fire protection system composed of detecting, warning, and extinguishing devices that do not create a hazardous environment to all spacecraft volumes during all mission phases.		
9.8.2.2	Fire Protection System Health and Status	[V2 9060]	The fire protection system health and status data shall be provided to the crew and other mission systems.		
9.8.2.3	Fire Protection System Failure Alerting	[V2 9061]	The vehicle shall be alert the crew of failures to the fire protection system.		
9.8.2.4	Fire Protection System Activation	[V2 9062]	The fire protection system shall be capable of being manually activated and deactivated.		
9.8.2.5	Portable Fire Extinguishers	[V2 9063]	A fire protection system shall include manually operated portable fire extinguishers usable while wearing the most encumbering equipment and clothing anticipated.		
9.8.3	Emergency Equipment Accessibility	[V2 9064]	Emergency equipment shall be clearly identified, accessible, and useable to complete emergency response in the time required during all mission phases where the corresponding emergency		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			may occur while wearing the most encumbering equipment and clothing anticipated.		
10.1.1	Crew Interface Consistency	[V2 10005]	The system shall provide crew interfaces that are consistent in appearance, arrangement, location, and operation throughout systems.		
10.1.2	Operations Nomenclature Standardization	[V2 10006]	Operational nomenclature shall be standardized throughout a system.		
10.1.3	Display Standards	[V2 10150]	The system shall meet the Display Standard in Appendix F.		
10.1.4	Labeling Plan and Icon Library	[V2 10151]	The system shall provide labels that are consistent with a Labeling Plan and Icon Library as established by the program.		
10.2.1	Stale, Missing, or Unavailable Data	[V2 10020]	The system shall provide visual indication when a data parameter is stale, missing, unavailable, or unknown.		
10.2.2	Maximum System Response Times	[V2 10022]	The system shall provide positive indication of crew-initiated control within the times specified in Table 10.2-1—Maximum System Response Time(s).		
10.2.3	System Latency for Piloting	[V2 10152]	The system shall provide a display system latency for information elements used in vehicle manual flight control tasks and the monitoring of time critical automated flight control tasks, including translation and rotation, that does not exceed a delay of 50ms.		
10.2.4	Command Confirmation	[V2 10080]	The system shall require operator confirmation before completing critical, hazardous, irreversible, or destructive commands.		
10.2.5	Mode Change Command	[V2 10153]	The system shall require an explicit command to change between simulation, test, or operational mode.		
10.2.6	Critical Information Design	[V2 10113]	The system shall provide data critical to mission planning, mission operations, system maintenance, and system health and status at an appropriate level of detail in a form that does not require mental transposition or computation, memory, or repetitive navigation.		
10.2.7	Data Update Rates	[V2 10123]	The system shall operate at a rate that enables the crew to perform tasks effectively and efficiently, e.g., within acceptable error limits and scheduled operating times.		
10.2.8	Data Availability	[V2 10124]	The system shall provide the crew with data to perform tasks at each workstation where those tasks are to be performed.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
10.2.9	Information Management Security	[V2 10125]	The system shall have features for the protection of sensitive and private data, transmission, secure viewing, and sender verification.		
10.2.10	Information Management Ground Access	[V2 10126]	The system shall allow for ground access to perform all onboard database functions without crew intervention.		
10.2.11	Information Backup and Restoration	[V2 10129]	The system shall provide for 1) automatic backup and crew restoration of information essential for system functionality, and 2) crew-initiated backup and restoration of information that can be generated or changed by crew during the mission.		
10.2.12	Alternative Information Sources	[V2 10130]	The system shall provide alternative information sources for use in the event of the loss of the information management system.		
10.2.13	Software System Recovery	[V2 10131]	The system shall be rapidly recoverable from a software system crash.		
10.3.1	Distinguishable and Consistent Alerts	[V2 10114]	The system shall provide distinct visual and audio annunciations to the human operators for emergency, warning, and caution events which require human operator action, and advisory alerts that are necessary for human operator situation awareness as specified in Table 10.3-1—Table Alert Type and Annunciation Table.		
10.3.2	Alert Prioritization	[V2 10175]	The System shall prioritize alerts per Table 10.3-1—Table Alert Type and Annunciation Table.		
10.3.3	Reduced Initial Alert Annunciation Level	[V2 10176]	The System shall provide a “pre-alert” for auditory annunciations whereby the same alarm is annunciated 10dB lower than its final calibrated level.		
10.3.4	Parameter Notifications	[V2 10115]	The system shall notify the human operators if the selected system parameters are outside of tolerance.		
10.3.5	Alert Signal Enable	[V2 10154]	The system shall allow alert functions to be enabled by human operator.		
10.3.6	Alert Signal Inhibit	[V2 10155]	The system shall allow the human operator to inhibit alert functions that are Out-of-Service (OoSVC).		
10.3.7	Alert Inhibit Audit	[V2 10156]	The system shall perform an audit and report all alerts that are in inhibited status to the human operators.		
10.3.8	Alert Signal Suppress	[V2 10177]	The system shall allow the human operator to suppress the audio and visual alert annunciations.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
10.3.9	Manual Activation of Emergency Responses	[V2 10178]	The system shall provide manual activation of emergency responses that is independent of display function.		
10.3.10	Alert Silencing	[V2 10116]	The system shall provide a manual silencing feature for active audio annunciations.		
10.3.11	Crew Test for Annunciation Failures	[V2 10117]	The system shall test for a failure of the visual and auditory annunciators upon crew request.		
10.3.12	Auditory Alert Frequency	[V2 10058]	Frequency content of auditory alerts shall correspond to maximal human sensitivity (200 Hz to 4 kHz).		
10.3.13	Alert Sound Level	[V2 10056]	The system shall produce non-speech auditory annunciations with an SPL that meets at least one of the following criteria: a. Using measurements of A-weighted sound levels (ISO 7731:2003(E), Ergonomics – Danger signals for public and work areas – Auditory danger signals, method a in section 5.2.2.1), the difference between the two A-weighted SPLs of the signal and the ambient noise is greater than 15 dBA (LS,A to LN,A > 15 dBA). This method must be used for alarms intended to wake sleeping crewmembers, with the loudspeaker alarm volume adjusted to its minimum setting. b. Using measurements of octave band SPLs (ISO 7731:2003(E), method b in section 5.2.3.1), the SPL of the signal in one or more octave bands is greater than the effective masked threshold by at least 10 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,oct to Lti,oct > 10 dB). c. Using measurements of 1/3-octave band SPLs (ISO 7731:2003(E), method c in section 5.2.3.2), the SPL of the signal in one or more 1/3-octave bands is greater than the effective masked threshold by 13 dB in the frequency range from 250 Hz to 4,000 Hz (LSi,1/3oct to LTi,1/3oct > 13 dB).		
10.4.1.1	Display and Control Grouping	[V2 10032]	The system shall provide displays and controls whose relationships are logical, explicit, and/or grouped according to purpose, function, or sequence.		
10.4.1.2	Display and Control Movement Compatibility	[V2 10034]	Displays shall be compatible with control movement and the resulting system response as defined in Table 10.4-1—Hardware and Software Controls.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
10.4.2.1	Simultaneous Display of Critical Information	[V2 10037]	The system shall provide the display area to simultaneously present all critical task information required within the operator's field of regard.		
10.4.2.2	Color Coding Redundancy	[V2 10045]	The system shall provide an additional cue when color is issued to convey meaning for critical information or for a critical task.		
10.4.2.3	Measurement Units	[V2 10046]	The system shall use consistent units of measure that are displayed for each numerical value, or for each group of numeric values where the units are the same.		
10.4.2.4	Visual Display Parameters	[V2 10048]	The system shall provide IVA displays that meet the visual display requirements in Table 10.4-2—Visual Display Parameters.		
10.4.2.5	Indicator Light Characteristics	[V2 10201]	The system shall implement indicator lights that meet the characteristics shown in Table 10.4-3—Indicator Light Characteristics.		
10.4.3.1	Label Provision	[V2 10060]	The system shall provide labels for the crew to identify items, interpret and follow nominal and contingency procedures, and avoid hazards.		
10.4.3.2	Label Location	[V2 10063]	The system shall provide labels that are positioned on or directly adjacent to the item they are labeling.		
10.4.3.3	Label Font Height	[V2 10066]	The system shall provide labels that have a minimum font height of 12-point or 0.4 degrees in expected operating positions.		
10.4.4.1	Out-of-View Control Identification	[V2 10068]	Controls that are intended for out-of-view operation shall be spatially or tactually distinct from one another.		
10.4.4.2	Hazardous Control Coding	[V2 10069]	The system shall provide coding for hazardous or irreversible controls that are distinguishable from non-emergency controls.		
10.4.4.3	Control Spacing	[V2 10070]	The system shall provide spacing between IVA controls that meets the criteria in Table 10.4-4—Control Spacing.		
10.4.4.4	Connector Spacing	[V2 10157]	The system shall provide spacing between IVA connecters that is at least: a. 25 mm (1 in) if operated with bare fingers, b. 32 mm (1.25 in) if operated with unpressurized gloved fingers, c. 64 mm (2.5 in) if must be "gripped firmly" with multiple fingers.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
10.4.4.5	Control Operation Supports and Restraints	[V2 10073]	The system shall provide body or limb supports and restraints that enable accurate crew control of applicable interfaces and prevent inadvertent control inputs during expected gravity, acceleration, and vibration conditions.		
10.4.4.6	Moderate-g Control Configuration	[V2 10158]	The system shall place controls used during accelerations between 2g and 3g so that the operator can make control inputs via hand/wrist movements and forward reached within +/- 30-degree cone.		
10.4.4.7	High-g Control Configuration	[V2 10159]	The system shall place controls during accelerations above 3g so that the operator can make control inputs via hand/wrist movements without reaching.		
10.4.4.8	Manual Piloting Control Latency	[V2 10076]	The system shall provide controls for the execution of manual piloting such that latencies will be less than 100ms for high gain tasks and less than 200ms for low gain piloting tasks.		
10.4.4.9	Manual Piloting Control Latency Variability	[V2 10160]	The system shall provide controls for the execution of manual piloting such that latencies have a minimum variability.		
10.4.4.10	Control Resistive Force	[V2 10077]	Control resistive force shall prevent unintended drifting or changing of position.		
10.4.4.11	Detent Controls	[V2 10078]	The system shall provide detent controls when control movements occur in discrete steps.		
10.4.4.12	Stops Controls	[V2 10079]	The system shall provide stops at the beginning and end of a range of control positions, if the control is not required to be operated beyond the end positions or specified limits.		
10.5.1.1	Intelligibility of Electronically Stored Speech Messages	[V2 10052]	Electronically stored speech messages from audio displays shall have 100% intelligibility and discriminability between the ensemble of different messages the audio display is programmed to produce (as measured under realistic background noise conditions and at locations where the display will be used).		
10.5.1.2	Reverberation Time	[V2 10057]	The system shall provide a reverberation time of less than 0.6 seconds within the 500-Hz, 1-kHz, and 2-kHz octave bands.		
10.5.2.1	Communication System Design	[V2 10083]	Communication systems shall be designed to support coordinated and collaborative distributed teamwork.		
10.5.2.2	Communication Capability	[V2 10084]	The system shall provide the capability to send and receive communication among crewmembers, spacecraft systems, and		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			ground systems to support crew performance, behavioral health, and safety.		
10.5.2.3	Communication Speech Levels	[V2 10085]	Audio communication systems shall allow crew to communicate with one another and with the ground at normal speech levels and with expected background SPLs.		
10.5.2.4	Speech Intelligibility	[V2 10091]	For critical communications, the system shall ensure 90% English word recognition, using ANSI/ASA S3.2-2009, Method for Measuring the Intelligibility of Speech over Communication Systems.		
10.5.2.5	Private Audio Communication	[V2 10093]	The system shall provide the capability for two-way private audio communication with the ground.		
10.5.3.1	Video Communications Visual Quality	[V2 10094]	Video communications shall employ digital encoding or alternate coding of equivalent visual quality.		
10.5.3.2	Video Communications Spatial Resolution	[V2 10095]	Video communications shall provide sufficient spatial resolution (width and height in pixels) to accomplish relevant tasks.		
10.5.3.3	Video Communications Temporal Resolution	[V2 10096]	Video communications shall provide sufficient temporal resolution (frames/s) to accomplish relevant tasks.		
10.5.3.4	Video Communications Color and Intensity	[V2 10097]	Video communications shall provide sufficient color and intensity levels to accomplish relevant tasks.		
10.5.3.5	Video Communications Bit Rate	[V2 10098]	Video communications systems shall support bit rates high enough to ensure that compression artifacts are as low as reasonably achievable.		
10.5.3.6	Audio-Visual Lag Time	[V2 10099]	Communications systems that carry sound and video that are intended to be synchronized shall ensure that the sound program does not lead the video program by more than 15 ms or lag the video program by more than 45 ms.		
10.6.1	Automation System Status Provision	[V2 10161]	The automated system shall provide the human operator with the following information: a. system state (e.g., position, location, hazardous condition, running, paused, faulted, completed, overridden, stopped, readiness)		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			b. projection of future state, including failure or decrements in performance (e.g., battery power versus traverse distance and assessment of uncertainty in projection of future state) and mode (e.g., Full/Partial/Manual/Test) c. system health d. configuration information (e.g., setup/input parameters, initial conditions, and terminating conditions)		
10.6.2	Automation Mode Change Notification	[V2 10162]	The system shall notify the human operator of mode changes of any safety-critical operations.		
10.6.3	Automation Data Availability	[V2 10163]	Automated or robotic systems shall record and make available operational and performance data to both crew and ground support personnel.		
10.6.4	Automation System Responsibility Delineation	[V2 10164]	Automated systems shall indicate whether a human operator or system is expected to perform a particular operation at a specific time.		
10.6.5	Automation and Robotics Override and Shut-Down Capabilities	[V2 10165]	Automated or robotic systems shall provide the human operator the ability to modify system configuration within the safety and performance limits of the system.		
10.6.6	Automation System Configuration	[V2 10166]	Automated or robotic systems shall provide the human operator the ability to modify system configuration within the safety and performance limits of the system.		
10.6.7	Range of Control	[V2 10167]	Automated or robotic systems shall provide the human operator with a range of control options that accommodates the expected operating conditions.		
10.6.8	Automation Failure Recovery	[V2 10168]	The automated or robotic system shall enable the human operator to safely assume control of the system if a failure occurs or there is an inability to function (e.g., beyond designed ability).		
10.6.9	Decision Support	[V2 10169]	The automated or robotic system shall allow the human operator to determine when to use a decision aid and which decision aiding strategy to employ.		
10.6.10	Decision Aid Clarity	[V2 10170]	Decision aid systems shall provide explanations and rationales, and consequences of potential actions.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
10.6.11	Decision Aid Failure Notification	[V2 10171]	Decision aids shall notify the human operator when a problem or situation is beyond the aid's capability.		
10.6.12	Automation Safe Mode	[V2 10172]	The automated or robotic system shall take protective action (e.g., avoidance maneuver, protective stop) or request that the operator safely take control if the system's operational safety threshold is exceeded.		
10.6.13	Safety Default	[V2 10173]	The automated or robotic system shall maintain safe operations if the human operator does not assume control when requested.		
10.6.14	System Initiation	[V2 10174]	Autonomous robotic systems shall be initiated only by human operators, including restart after an emergency or protective stop.		
11.1.1	Suited Donning and Doffing	[V2 11001]	The system shall accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations.		
11.1.2	Suit Materials Compatibility	[V2 11125]	Pharmaceuticals, topical treatments and cleaning materials shall be compatible with suit materials (internally and externally).		
11.1.3	Suit Materials Cleanability	[V2 11126]	The suit materials (internally and externally) shall be compatible with the expected cleaning materials and methods.		
11.1.4.1	Suit Pressure Set-Points	[V2 11006]	The suit shall provide the capability for the crewmember to select discrete suit pressure set-points within the suit operating pressure ranges during pressurized and unpressurized suited operations.		
11.1.4.2	Suit Equilibrium Pressure	[V2 11007]	Suits shall maintain pressure within 1.72 kPa (0.25 psi) after the suit has achieved an equilibrium pressure for a set-point.		
11.1.4.3	Continuous Noise in Spacesuits	[V2 11009]	Suits shall limit suit-induced continuous noise exposure at the ear to NC-50 or below without the use of auxiliary hearing protection.		
11.1.4.4	EVA Suit Radiation Monitoring	[V2 11010]	The suit shall provide or accommodate radiation monitoring and alerting functions to allow the crew to take appropriate actions.		
11.1.4.5	Suited Crewmember Heat Storage	[V2 11011]	The system shall prevent the energy stored by each crewmember during nominal suited operations from exceeding the limits defined by the range 3.0 kJ/kg (1.3 Btu/lb) > ΔQ stored > 1.9 kJ/kg (-0.8 Btu/lb), where ΔQ stored is calculated using the 41 Node Man or Wissler model.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
11.1.5.1	Suited Body Waste Management – Provision	[V2 11013]	Suits shall provide for management of urine, feces, menses, and vomitus of suited crewmembers.		
11.1.5.2	EVA Suit Urine Collection	[V2 11028]	EVA suits shall be capable of collecting a total urine volume of Vu = 0.5 +2.24t/24 L, where t is suited duration in hours.		
11.1.5.3	LEA Suit Urine Collection	[V2 11014]	LEA suits shall be capable of collecting a total urine volume of Vu = 0.5 + 2t/24 L throughout suited operations, where t is suited duration in hours.		
11.1.5.4	Suit Urine Collection per Day – Contingency	[V2 11015]	For contingency suited operations lasting longer than 24 hours, suits shall be capable of collecting and containing 1 L (33.8 fl oz) of urine per crewmember per day.		
11.1.5.5	Suit Feces Collection per Day – Contingency	[V2 11016]	During contingency suited operations, suits shall be capable of collecting 75 g (0.17 lb) (by mass) and 75 mL (2.5 fl oz) (by volume) of fecal matter per crewmember per day.		
11.1.5.6	Suit Isolation of Vomitus	[V2 11017]	Suits shall be shown to not create any catastrophic hazards in the event of vomitus from the crewmember.		
11.1.6.1	Suited Field of Regard	[V2 11018]	Suits shall provide a field of regard sufficient to allow the crewmember to accomplish required suited tasks.		
11.1.6.2	Suit Helmet Optical Quality	[V2 11019]	Suit helmets shall have sufficient optical qualities to allow the crewmember to accomplish required suited tasks and maintain a level of SA necessary to maintain safety.		
11.1.6.3	Suit Helmet Luminance Shielding	[V2 11020]	Suit helmets shall provide protection to suited crewmembers from viewing objects with luminance that could prevent successful completion of required suited tasks.		
11.1.6.4	Suit Helmet Visual Distortions	[V2 11021]	Suit helmets shall be free from visual distortion.		
11.1.6.5	Suit Helmet Displays	[V2 11022]	Suit helmet field of regard shall be unencumbered if helmet- or head-mounted displays are provided.		
11.1.7	Suit Information Management	[V2 11023]	The system shall allow the crewmember to effectively input, store, receive, display, process, distribute, update, monitor and dispose of relevant information on consumable levels, suit status and alerts, and biomedical data.		
11.1.8	Pressure Suits for Protection from Cabin Depressurization	[V2 11100]	The system shall provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			(such as in mission dockings, operations during periods of high incidence of micrometeoroids and orbital debris (MMOD) or complex vehicle maneuvers).		
11.2.1	Ability to Work in Suits	[V2 11024]	Suits shall provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.		
11.2.2	Suited Nutrition	[V2 11025]	The system shall provide a means for crewmember nutrition in pressure suits designed for surface (e.g., Moon or Mars) EVAs of more than 4 hours in duration or any suited activities greater than 12 hours in duration.		
11.2.3.1	LEA Suited Hydration	[V2 11029]	The system shall provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 2 L (67.6 fl oz) per 24 hours for the LEA suit.		
11.2.3.2	EVA Suited Hydration	[V2 11030]	The system shall provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 240 mL (8.1 fl oz) per hour for EVA suited operations.		
11.2.4	Suited Medication Administration	[V2 11027]	The system shall provide a means for administration of medication to a suited, pressurized crewmember for pressurized suited exposures greater than 12 hours.		
11.2.5	Suited Relative Humidity	[V2 11031]	For suited operations, the system shall limit RH to the levels in Table 11.2-1—Average Relative Humidity Exposure Limits for Suited Operations.		
11.2.6	LEA Suited Decompression Sickness Prevention Capability	[V2 11032]	LEA spacesuits shall be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.		
11.3.1	Suited Thermal Control	[V2 11033]	The suit shall allow the suited crewmembers and remote operators to adjust the suit thermal control system.		
11.3.2	Suited Atmospheric Data Recording	[V2 11034]	Systems shall automatically record suit pressure, ppO_2, and $ppCO_2$.		
11.3.3	Suited Atmospheric Data Displaying	[V2 11035]	Suits shall display suit pressure, ppO_2, and $ppCO_2$ data to the suited crewmember.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
11.3.4	Suited Atmospheric Monitoring and Alerting	[V2 11036]	Suits shall monitor suit pressure, ppO_2, and $ppCO_2$ and alert the crewmember when they are outside safe limits.		
11.3.5	Nominal Spacesuit Carbon Dioxide Levels	[V2 11039]	The spacesuit shall limit the inspired CO_2 partial pressure ($PICO_2$) in accordance with Table 11.3-1—Spacesuit Inspired Partial Pressure of CO_2 ($PICO_2$) Limits.		
11.3.6	Contingency Spacesuit Carbon Dioxide Levels for Partial Gravity Scenarios	[V2 11040]	The spacesuit inspired CO_2 partial pressure ($PiCO_2$) shall not exceed 20 mmHg during contingency scenarios up to a duration of 1-hour.		
11.4.1	EVA Suited Metabolic Rate Measurement	[V2 11037]	The system shall measure or calculate metabolic rates of suited EVA crewmembers.		
11.4.2	EVA Suited Metabolic Data Display	[V2 11038]	The system shall display metabolic data of suited EVA crewmembers to the crew.		
11.5	Incapacitated Crew Rescue (ICR)	[V2 11101]	Resources shall be provided to rescue an incapacitated suited crewmember(s).		
12.1.1	System Assumptions	[V2 12003]	Each human spaceflight program shall document the system support design and environment: a. Work environment (e.g., lighting, heating, atmosphere, gravity) b. Tools and support equipment c. Ground support personnel characteristics (e.g., size, training, experience, number, physical and cognitive capabilities, skills, ergonomics) d. Ground support personnel tasks (e.g. environment, complexity, scheduling)		
12.1.2.1	Anthropometry, Biomechanics, Range of Motion, and Strength	[V2 12004]	Each program shall identify an anthropometry, biomechanics, range of motion, and strength data set for the ground support population to be accommodated in support of all requirements in this section of this NASA Technical Standard.		
12.1.2.2	Protective Equipment	[V2 12005]	The system shall accommodate ground personnel protective equipment and attire.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
12.1.2.3	Volume Accommodation	[V2 12006]	The system shall provide the volume necessary for the ground support personnel to perform all ground processing tasks using the required tools and equipment.		
12.1.2.4	Ground Processing – Induced Forces	[V2 12007]	Systems, hardware, and equipment shall be protected from or be capable of withstanding forces imposed by the ground support personnel or ground support equipment (GSE), in a 1-g environment.		
12.1.2.5	Systems Accessibility	[V2 12008]	System components, hardware, and/or equipment that requires ground support personnel inspection or interaction shall be accessible.		
12.1.2.6	Tool Clearance	[V2 12009]	The system shall provide tool clearances for tool installation and actuation for all tool interfaces during ground processing.		
12.1.3.1	Flight Hardware Differentiation	[V2 12010]	Flight system components that have the same or similar form, but different functions shall not be physically interchangeable.		
12.1.3.2	Hardware Protection	[V2 12011]	The system shall provide a means of protecting flight hardware and equipment from damage during ground processing.		
12.1.3.3	Mobility Aids	[V2 12012]	The system shall provide mobility aids to support expected ground support personnel tasks.		
12.1.3.4	Equipment Handling Design	[V2 12013]	All items designed to be carried, supported, or removed and replaced shall have a means for grasping, handling, and carrying.		
12.1.3.5	Inadvertent Operation Prevention	[V2 12014]	The system shall be designed to prevent inadvertent operation of controls during ground processing.		
12.1.3.6	Incorrect Installation Prevention	[V2 12015]	System hardware and equipment shall be designed to prevent incorrect mounting or installation.		
12.1.3.7	Pre-Defined Tool Set	[V2 12016]	The system shall be designed to be assembled, prepared for launch, maintained, and reconfigured using a pre-defined set of standard tools and lesser set of any pre-established set of specialized tools.		
12.1.3.8	Captive Fasteners	[V2 12017]	Fasteners on installable units shall be captive.		
12.1.3.9	Ground Processing Without Damage	[V2 12018]	The system shall be designed for assembly, testing and checkout, troubleshooting, and maintenance that prevents damage to other components.		
12.1.3.10	Replaceable Items	[V2 12019]	The system shall locate maintenance items so that a planned ground processing or corrective or preventive maintenance task		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
			does not require the deintegration or demating of other systems or components.		
12.1.3.11	Visual Access for Ground Processing	[V2 12020]	The system shall provide direct line-of-sight visual access to all flight system components requiring inspections or other human-system interactions, except self-mating connectors, on which ground processing is performed by ground personnel.		
12.1.3.12	Lighting	[V2 12021]	The flight system in combination with ground support equipment shall provide lighting to perform ground processing tasks in the vehicle.		
12.1.3.13	Supplemental Systems	[V2 12022]	The system shall be designed to support any supplemental systems that are required to assist ground support personnel when an assigned task cannot reliably, safely, or effectively be performed by ground support personnel alone.		
12.1.3.14	Operational Consistency	[V2 12023]	The system shall be designed for consistent operation across ground processing tasks.		
12.1.3.15	Restraints and Platforms	[V2 12024]	The system shall accommodate restraint and platform placement that ensures the reach and work envelope of the suited or unsuited ground support personnel for the required tasks.		
12.1.3.16	System Feedback	[V2 12025]	The system shall provide feedback to the operator indicating successful task completion.		
12.1.3.17	Stowage Access	[V2 12026]	The system shall provide access for ground support personnel to spacecraft stowage volumes that require late loading and early unloading of items.		
12.1.3.18	Flight Software Systems	[V2 12027]	The system shall allow the ground support personnel safe operation of flight software systems for ground processing.		
12.1.4.1	Sharp Edge and Burr Injury Prevention	[V2 12028]	The system shall protect ground support personnel from injury resulting from sharp edges and burrs.		
12.1.4.2	Pinch Point Prevention	[V2 12029]	The system shall be designed to protect ground personnel from injury due to pinch points.		
12.1.4.3	Hazard Controls	[V2 12030]	The system shall be designed to prevent unnecessary exposure of ground support personnel and equipment to hazards, including spills, electrical shocks, and the release of stored energy.		
12.1.4.4	System Safing for Ground Operations	[V2 12031]	The system shall alert and allow ground personnel to safe the system before performing any ground operation.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
12.1.4.5	Contamination Controls	[V2 12032]	The system shall have controls in place to prevent the introduction of contaminants to the flight vehicle.		
12.1.4.6	Containment of Fluids and Gases	[V2 12033]	The system shall provide for containment and disposal of fluids and gases inadvertently released into the flight system.		
12.1.4.7	Safe Weight Limit	[V2 12034]	Hardware and equipment installed or removed by ground support personnel without ground support equipment shall be less than a safe weight limit.		
12.1.4.8	Safe Flight System Component Arrangement	[V2 12035]	Flight system components shall be arranged, or located to prevent hazards, interference, or errors during concurrent ground processing tasks.		
12.1.5.1	Connector Design and Spacing	[V2 12036]	Connectors shall be designed and spaced to allow for accurate, damage-free mating and demating by ground support personnel.		
12.1.5.2	Connector Incorrect Mating Prevention	[V2 12037]	Connectors shall have physical features to preclude incorrect mating and mismating. This can be accomplished by differing connector shell sizes, differing connector keyway arrangements, and having different contact arrangements (these are listed in order of most preferred to least preferred).		
12.1.6.1	Label Provisions	[V2 12038]	Labels and placards shall be provided for the ground support personnel to identify items, interpret and follow procedures, and avoid hazards.		
12.1.6.2	Label Standardization	[V2 12039]	Labels and placards shall be consistent and standardized throughout the system.		
12.1.6.3	Label Content	[V2 12040]	The content of labels and placards shall be of sufficient size, color contrast, and character height and style to support readability.		
12.1.6.4	Readable Label Positioning	[V2 12041]	Labels and placards shall be located such that they are readable by the operator, considering ambient lighting conditions, orientation in the integrated configuration, and position of the operator relative to the label.		
12.1.6.5	Non-Obstructive Labels	[V2 12042]	Labels, placards, or part markings used for ground processing shall not visually or operationally interfere with spaceflight crew interface labeling.		
12.2.1	Emergency Egress at the Launch Site	[V2 12043]	The system shall be designed such that the spaceflight crew and ground support personnel can egress within the time required to preserve the health and safety of all spaceflight crew and ground support personnel in the event of an emergency.		

Section	Title	Number	Requirement Text	Applicable (Enter Yes or No)	Comments
12.2.2	Emergency Egress to Medical Care	[V2 12044]	The system shall be designed to ensure spaceflight crew and ground support personnel can egress to a location providing advanced pre-hospital life support.		
12.2.3	Nominal Timely Egress	[V2 12045]	Following a post mission nominal landing, launch scrub, or abort scenario, crew egress from the system shall be expedited to ensure crew health.		
12.2.4	Emergency Egress Acceleration Limits	[V2 12046]	For ground emergency egress systems (EES), the system shall limit the magnitude and direction of crew exposure to accelerations according to Table 12.1-1—EES Acceleration Limits – Sustained, and Table 12.1-2—EES Acceleration Limits – Jerk.		

APPENDIX E

PHYSICAL CHARACTERISTICS AND CAPABILITIES DATA SETS

E.1 PURPOSE

A system designed for human use or habitation must accommodate the range of human characteristics and capabilities relevant to the system and operating environment for the NASA-defined crew population. The datasets provided include characteristics and capabilities for anthropometric dimensions, range of motion, strength, mass, volume, and surface area. The datasets and their supplemental information take into account human characteristics such as age, sex, and physical condition as well as mission characteristics such as clothing and suit pressurization.

The intent of the technical requirements in Section 4 is to accommodate the entire potential user population, not just meet the criteria in the datasets provided, which provide the most frequently used values. Identification of a design criteria not provided in the tables needs coordination and concurrence from NASA Stakeholders. Each dataset may be tailored by NASA based on program or mission specific criteria. Guidance on the evaluation of design for physical characteristics and capabilities can be found in NASA/TP-2014-218556, Human Integration Design Process (HIDP).

E.2 ANTHROPOMETRIC DIMENSIONS

The data in the tables are from the population in the 1988 Anthropometric Survey of US Army Personnel (ANSUR) (ref. Natick/TR-89/044), projected forward by NASA to 2015 to account for the expected small growth in the size of members of the US population. Note that for measurements that include the length of the spine, 3% of stature (for standing measurements) or 6% of seated height (for sitting measurements) must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation of 3% and 6% values can be found in OCHMO-HB-004, Anthropometry, Biomechanics, and Strength.

These dimensions must be considered in light of garments, space adaptive postures and personal protective equipment that is expected to be used per task, and environmental conditions.

E.2.1 References

Gordon, C.C., Churchill, T., Clauser, C.E., Bradtmiller, B., McConville, J.T., Tebbetts, I., Walker, R.A. (1989). 1988 Anthropometric survey of U.S. army personnel: methods and summary statistics. NATICK/TR-89/044, United States Army Natick Research, Development and Engineering Center, Massachusetts.

Table E.2-1—Anthropometric Dimensions

Critical Dimension	Application Example	Minimal Clothing	
		Min (cm, (in))	Max (cm, (in))
Stature, Standing[3]	Maximum vertical clearance	148.6 (58.5)	194.6 (76.6)
Sitting Height[2]	Vertical seating clearance	77.7 (30.6)	101.3 (39.9)
Eye Height, Sitting[2]	Placement of panels to be within line-of-sight	66.5 (26.2)	88.9 (35.0)
Acromial Height, Sitting[2]	Top of seatback	49.5 (19.5)	68.1 (26.8)
Thigh Clearance, Sitting	Placement of objects that may be overlap (panels, control wheel, etc.)	13.0 (5.1)	20.1 (7.9)
Knee Height, Sitting	Height of panels in front of subject	45.5 (17.9)	63.5 (25.0)
Popliteal Height, Sitting	Height of seat pan	33.0 (13.0)	50.0 (19.7)
Wrist Height, Sitting (with arm to the side)	Downward reach of subject	39.6 (15.6)	54.6 (21.5)
Biacromial Breadth	Placement of restraint straps	32.3 (12.7)	44.5 (17.5)
Bideltoid Breadth	Width of seatback	37.8 (14.9)	56.1 (22.1)
Forearm-Forearm breadth	Side clearance envelope, possible seatback width	38.9 (15.3)	66.0 (26.0)
Hip Breadth, Sitting[1]	Width of seat pan	31.5 (12.4)	46.5 (18.3)
Buttock-Popliteal Length, Sitting	Length of seat pan	42.2 (16.6)	57.2 (22.5)
Buttock-Knee Length, Sitting	Placement of panels in front of subject	52.1 (20.5)	69.9 (27.5)
Foot Length, Sitting	Rudder pedal design, foot clearance	21.6 (8.5)	30.5 (12.0)
Thumb Tip Reach, Sitting	Placement of control panels, maximum reach	65.0 (25.6)	90.9 (35.8)
Shoulder to Elbow Length	Placement and adjustability of hand controls; Vehicle reach access	29.6 (11.6)	41.9 (16.5)
Elbow to Center of Grip Length	Placement and adjustability of hand controls; Vehicle reach access	28.7 (11.3)	40.8 (16.1)
Hip Breadth, Standing[1]	Clearance while traversing and egressing the vehicle	29.8 (11.7)	40.6 (16.0)
Bust Depth, Standing	Clearance while traversing and egressing the vehicle	19.1 (7.5)	30.2 (11.9)
Waist depth	Placement and length of restraint straps	15.0 (5.9)	30.0 (11.8)
Hand Length	Placement and adjustability of hand controls; Vehicle reach access	15.8 (6.2)	22.1 (8.7)
Elbow to Wrist length	Placement and adjustability of hand controls; Vehicle reach access	22.5 (8.9)	33.1 (13.0)
Cervical Height, Standing[3]	Posture based clearance while traversing and egressing the vehicle	127.7 (50.3)	169.8 (66.9)
Trochanteric Height	Posture based clearance while traversing and egressing the vehicle	75.2 (29.6)	105.4 (41.5)

Ankle Height	Posture based clearance while traversing and egressing the vehicle	4.8 (1.9)	8.1 (3.2)
Acromion (Shoulder) Height, Standing[3]	Posture based clearance while traversing and egressing the vehicle	120.4 (47.4)	161.8 (63.7)

[1]The largest female hip breadth is larger than the largest male hip breadth, and the smallest male hip breadth is smaller than the smallest female hip breadth; therefore, male data are used for the Min dimension, and female data are used for the Max dimension.
[2] For measurements that include the length of the spine in sitting postures, 6% of the sitting measurement must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation 6% values can be found in OCHMO-HB-004, Anthropometry, Biomechanics, and Strength.
*[3] For measurements that include the length of the spine in standing postures, 3% the standing measurement must be added to allow for spinal elongation due to micro-gravity exposure. Additional information on the derivation 3% values can be found in OCHMO-HB-004, Anthropometry, Biomechanics, and Strength. *

E.3 RANGE OF MOTION

The ranges of motion to be accommodated for crewmembers were collected in 1 g conditions as part of a 2007/2008 study in the NASA JSC Anthropometry and Biomechanics Facility.

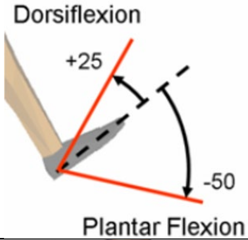
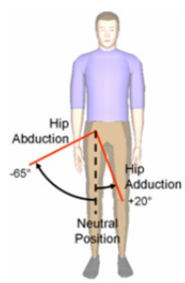
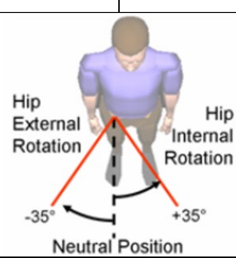
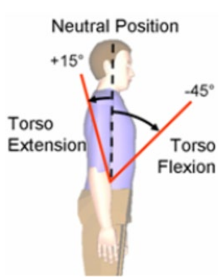
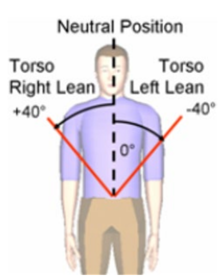
Table E.3-1—Unsuited Range of Motion, provides several joint measures that were present in old versions of this table but were not reinvestigated as a part of the 2007/2008 mobility study. These values are specifically called out when listed in the table.

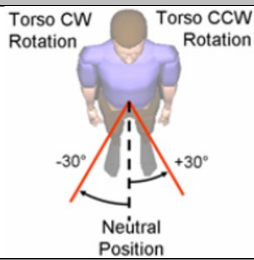
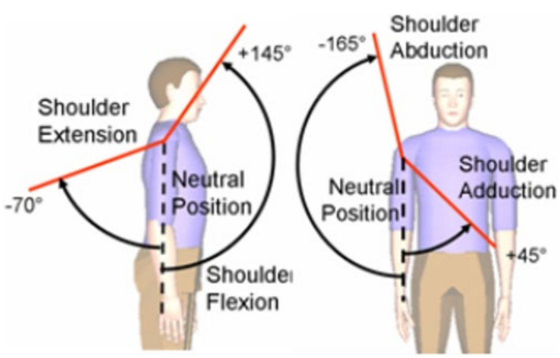
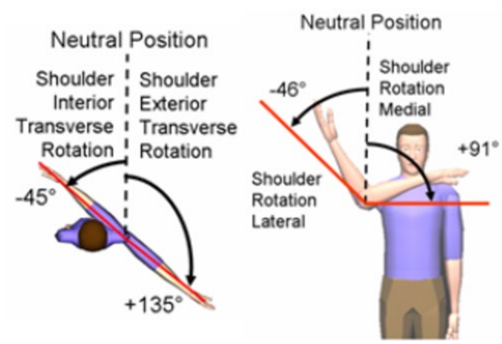
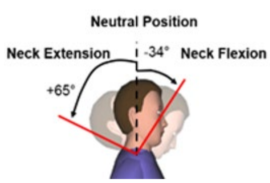
Tables E.3-2 and E.3-3 provide Range of Motion (ROM) for several joint measures under unpressurized and pressurized suit conditions. It should be noted that since pressurization causes severe restrictions to range of motion, no pressurized ROM for a LEA type suit is provided. Hence, pressurized ROM data are applicable only for an EVA type suit. The values represented in these tables show the level of mobility that was needed to perform a variety of relevant functional tasks performed using a hybrid representative EVA suit. These numbers do not necessarily indicate maximum level of mobility possible in a given configuration.

E.3.1 References

"1979 Study" refers to data from SP-2-86L-064 Thornton, W, and Jackson, J. Anthropometric Study of Astronaut Candidates, 1979 to 1980, (Unpublished Data) NASA-JSC.

Table E.3-1—Unsuited Range of Motion

<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Unsuited ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Ankle</td><td>Dorsiflexion</td><td>Plantar Flex</td></tr>
<tr><td>25</td><td>-50</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Knee</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>-125</td><td>0</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">
</td><td rowspan="6">Hip</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>165</td><td>-15</td></tr>
<tr><td>Abduction</td><td>Adduction</td></tr>
<tr><td>-65</td><td>20</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td>Internal Rotation</td><td>External Rotation</td></tr>
<tr><td>35</td><td>-35</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">
</td><td rowspan="4">Torso</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>-45</td><td>15</td></tr>
<tr><td>Right Lean</td><td>Left Lean</td></tr>
<tr><td>40</td><td>-40</td></tr>
</table>

<table>
<tr><th>Diagram</th><th>Anatomy</th><th colspan="2">Unsuited ROM (in degrees)</th></tr>
<tr><td rowspan="2">
</td><td rowspan="2"></td><td>CCW</td><td>CW</td></tr>
<tr><td>30</td><td>-30</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">Shoulder</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>145</td><td>-70</td></tr>
<tr><td>Abduction</td><td>Adduction</td></tr>
<tr><td>-165</td><td>45</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">Shoulder 1979 Study</td><td>Interior Transverse Rotation</td><td>Exterior Transverse Rotation</td></tr>
<tr><td>-45</td><td>135</td></tr>
<tr><td>Lateral</td><td>Medial</td></tr>
<tr><td>-46</td><td>91</td></tr>
<tr><td rowspan="4">

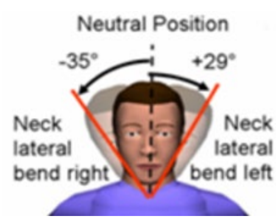
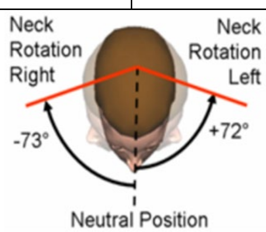
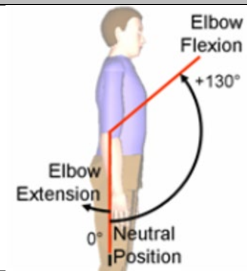
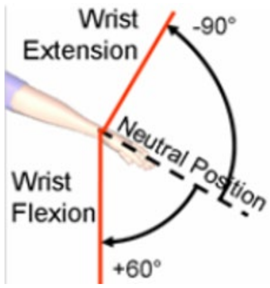
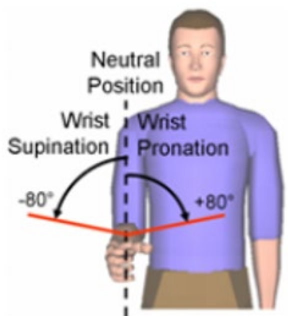
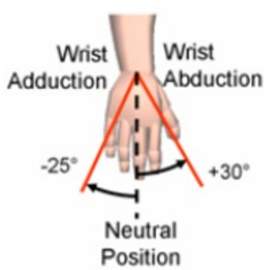
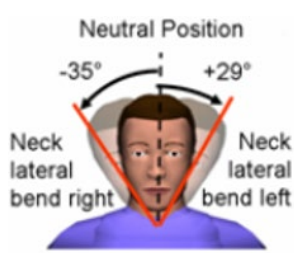
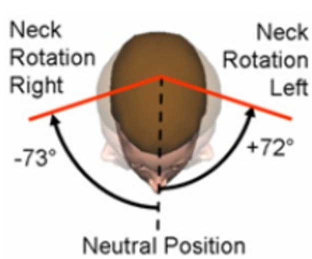

</td><td rowspan="6">Neck 1979 Study</td><td>Flex</td><td>Ex</td></tr>
<tr><td>65</td><td>-34</td></tr>
<tr><td>Bend Right</td><td>Bend Left</td></tr>
<tr><td>-35</td><td>29</td></tr>
<tr><td rowspan="2">
</td><td>Rotation Right</td><td>Rotation Left</td></tr>
<tr><td>-73</td><td>72</td></tr>
</table>

Diagram	Anatomy	Unsuited ROM (in degrees)	
	Elbow	Flexion	Extension
		130	0
 	Wrist	Extension	Flexion
		-90	60
		Abduction (Radial Deviation)	Adduction (Ulnar Deviation)
		30	-25
		Supination	Pronation
		-80	80
 	Neck 1979 Study	Flex	Ex
		-65	34
		Bend Right	Bend Left
		-35	29
		Rot R	Rot L
		-73	72

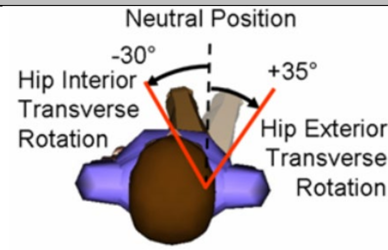
<table>
<tr><th rowspan="2">Diagram</th><th rowspan="2">Anatomy</th><th colspan="2">Unsuited ROM (in degrees)</th></tr>
<tr></tr>
<tr><td rowspan="2">
</td><td rowspan="2">Hip
1979 Study</td><td>Interior Transverse Rotation</td><td>Exterior Transverse Rotation</td></tr>
<tr><td>-30</td><td>35</td></tr>
</table>

Table E.3-2—Suited/Unpressurized Range of Motion

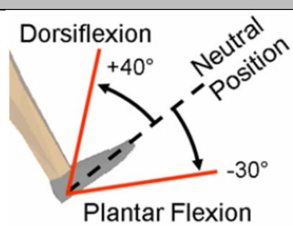
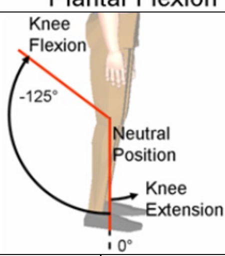
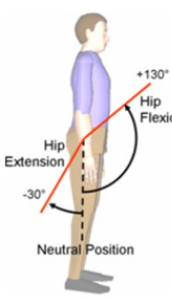
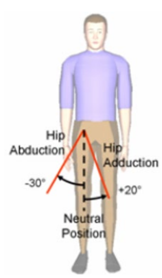
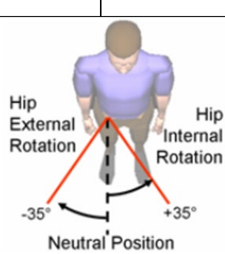
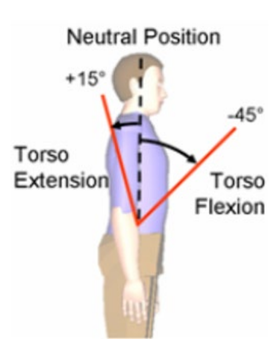
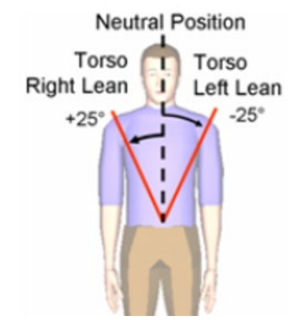
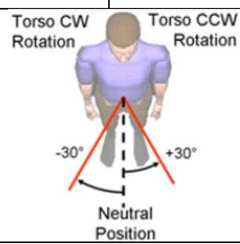
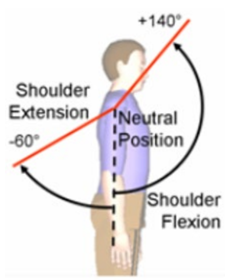
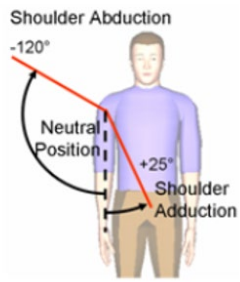
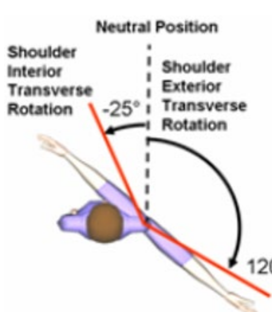
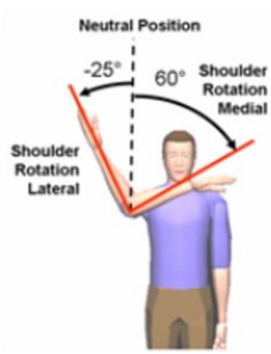
<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Ankle</td><td>Dorsiflexion</td><td>Plantar Flex</td></tr>
<tr><td>40</td><td>-30</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Knee</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>-125</td><td>0</td></tr>
<tr><td rowspan="4">
</td><td rowspan="4">
</td><td rowspan="6">Hip</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>130</td><td>-30</td></tr>
<tr><td>Abduction</td><td>Adduction</td></tr>
<tr><td>-30</td><td>20</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td>Internal Rotation</td><td>External Rotation</td></tr>
<tr><td>35</td><td>-35</td></tr>
</table>

Diagram	Anatomy	Suited Unpressurized ROM (in degrees)	
 	Torso	Flexion	Extension
		-45	15
		Right Lean	Left Lean
		25	-25
	Torso	CCW	CW
		30	-30
 	Shoulder	Flexion	Extension
		140	-60
		Abduction	Adduction
		-120	25
 	Addt'l Shoulder	Interior Transverse Rotation	Exterior Transverse Rotation
		-25	120
		Lateral	Medial
		-25	60

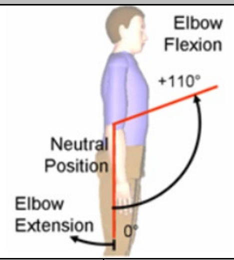
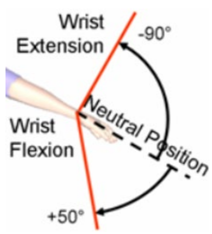
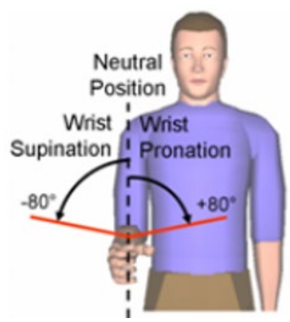
<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Elbow</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>110</td><td>0</td></tr>
<tr><td rowspan="3">
</td><td rowspan="6">
</td><td rowspan="6">Wrist</td><td>Extension</td><td>Flexion</td></tr>
<tr><td>-90</td><td>50</td></tr>
<tr><td>Abduction (Radial Deviation)</td><td>Adduction (Ulnar Deviation)</td></tr>
<tr><td rowspan="3">
</td><td>30</td><td>-30</td></tr>
<tr><td>Supination</td><td>Pronation</td></tr>
<tr><td>-80</td><td>80</td></tr>
</table>

Table E.3-3—Suited/Pressurized Range of Motion

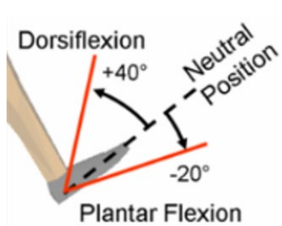
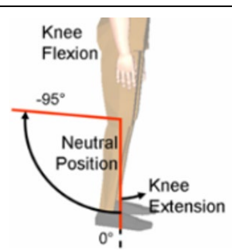
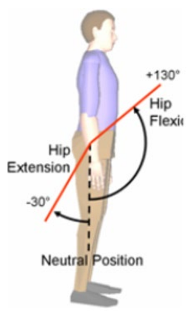
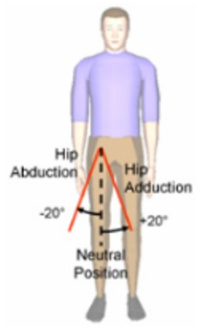
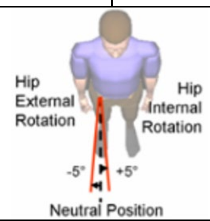
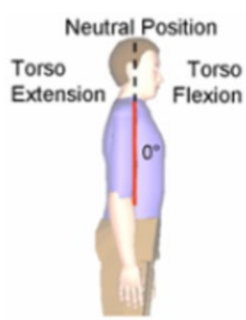
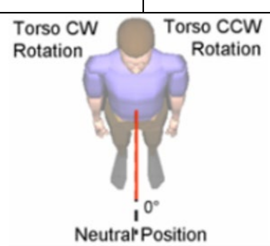
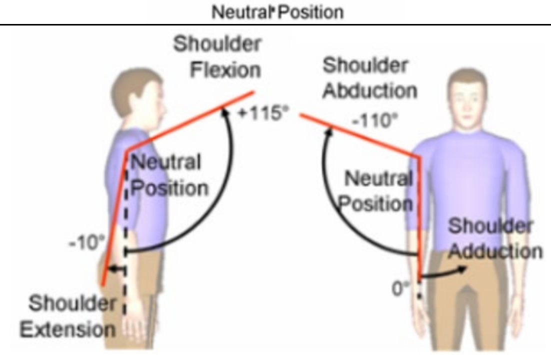
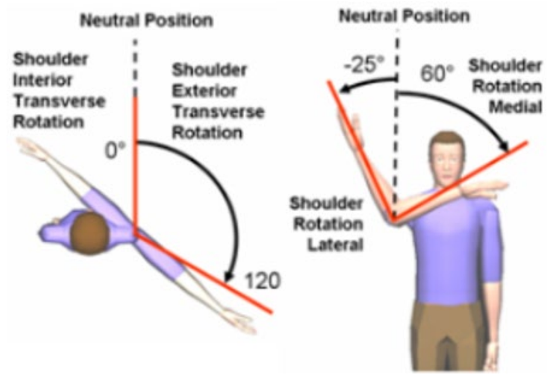
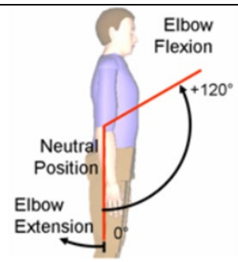
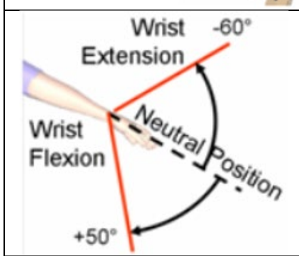
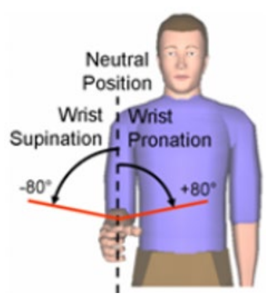
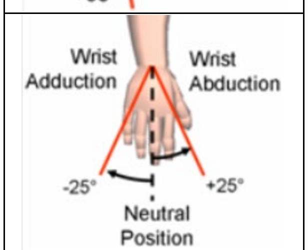
<table>
<tr><th>Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td rowspan="2">
</td><td rowspan="2">Ankle</td><td>Dorsiflexion</td><td>Plantar Flex</td></tr>
<tr><td>40</td><td>-20</td></tr>
<tr><td rowspan="2">
</td><td rowspan="2">Knee</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>-95</td><td>0</td></tr>
</table>

Diagram	Anatomy	Suited Unpressurized ROM (in degrees)	
 	Hip	Flexion	Extension
		130	-30
		Abduction	Adduction
		-20	20
		Internal Rotation	External Rotation
		5	-5
 	Torso	Flexion	Extension
		0	0
		Right Lean	Left Lean
		0	0
		CCW	CW
		0	0
	Shoulder	Flexion	Extension
		115	-10
		Abduction	Adduction
		-110	0

<table>
<tr><th colspan="2">Diagram</th><th>Anatomy</th><th colspan="2">Suited Unpressurized ROM (in degrees)</th></tr>
<tr><td colspan="2" rowspan="4">
</td><td rowspan="4">Addt'l Shoulder</td><td>Interior Transverse Rotation</td><td>Exterior Transverse Rotation</td></tr>
<tr><td>0</td><td>120</td></tr>
<tr><td>Lateral</td><td>Medial</td></tr>
<tr><td>-25</td><td>60</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td rowspan="2">Elbow</td><td>Flexion</td><td>Extension</td></tr>
<tr><td>120</td><td>0</td></tr>
<tr><td rowspan="3">
</td><td rowspan="6">
</td><td rowspan="6">Wrist</td><td>Extension</td><td>Flexion</td></tr>
<tr><td>-60</td><td>50</td></tr>
<tr><td>Abduction (Radial Deviation)</td><td>Adduction (Ulnar Deviation)</td></tr>
<tr><td rowspan="3">
</td><td>25</td><td>-25</td></tr>
<tr><td>Supination</td><td>Pronation</td></tr>
<tr><td>-80</td><td>80</td></tr>
</table>

E.4 BODY SURFACE AREA

Whole body surface areas were computed by using a simple linear regression equation developed by Gehan and George (1970), as applied to the NASA dataset. Anthropometric data within the NASA dataset is for an age truncated subset of participants from the 1988 Anthropometric Survey of the U.S. Army (ANSUR) projected forward to the year 2015. This database is considered the most representative dataset for the American astronaut population.

Data for all members of the NASA dataset (both male and female) was entered into the equations to calculate whole-body surface areas. From the resulting values, mean and standard deviation for each gender were used to calculate the 1st percentile female and 99th percentile male whole-body surface area values. The 1st percentile value represents the minimum and the 99th percentile value represents the maximum in Table E.4-1—Body Surface Area of a Crewmember.

E.4.1 References

Gehan, E.A., & George, S.L. (1970). Estimation of human body surface area from height and weight. Cancer Chemotherapy Reports, 54, 225-235.

Table E.4-1—Body Surface Area of a Crewmember

Crewmember Body Surface Area (cm^2, (in^2))	
Minimum	13,831 (2,144)
Maximum	24,282 (3,764)

E.5 BODY MASS

Crewmember whole-body mass, body-segment mass, center of mass location, and moment of inertia data are provided in Appendix E.5.

The anatomical axis system is based on skeletal landmarks and provides a consistent reference for the principal axes system and the center of volume/mass independent of body-segment orientation as described in McConville et al. (1980) and Young et al. (1983). The principal axis of inertia originates at the center of volume/mass.

Regression equations from McConville et al. (1980) and Young et al. (1983) were used to compute the Body-Segment Properties (BSP); however, because the sample sizes in these two studies were relatively small (31 and 46 subjects, respectively), this document uses data from the ANSUR database for input into the regression equations.

The regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used in their most simple form, which uses only the stature and weight of the subject to calculate the volume and moments of inertia. A Matlab code was written to identify all females with a small stature (based on the female data only) and all males with a large stature (based on the male data only) in the ANSUR database; from this extracted data, the lightest female and heaviest male were identified. These values were then used in the regression equations to compute the BSP. McConville and Young did not generate regression equations to predict all BSP presented in this report; however, presented below is a description and reasoning (based on the available data) of how each BSP presented here was generated.

For tables Whole-Body Mass of Crewmember, Body-Segment Mass Properties for the Male and Female Crewmember, and Whole-Body Center of Mass Location of the Male and Female Crewmember, minimum values correspond to a small female in mass, and maximum values correspond to a large male in mass, respectively. These values are considered to be representative of those for a small female and a large male crewmember, respectively.

E.5.1 Whole-Body Mass

Regressions equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the whole-body volume. Whole-body mass was calculated by assuming the density of the human flesh was homogeneous; a density value of 1 g/cm^3 was used. With a value of unity for the density, the mass values are numerically equal to their corresponding volume values.

E.5.2 Whole Body and Segments Center of Mass

Assuming that the human flesh was homogeneous, it can also be assumed that the center of volume is at the center of mass location. McConville et al. (1980) and Young et al. (1983) provided ranges for the location of the center of volume for the male and female, respectively, in each study. Because regression equations were not given for the center of volume, the range values from the McConville et al. (1980) and Young et al. (1983) studies were used here. Specific values for the locations of the center of mass with respect to the anatomical axes were taken from each study to form the range; specifically, the upper range was set by the male upper range, and the lower range was set by the female lower range.

E.5.3 Whole Body Moments of Inertia

Moments of inertia regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used.

E.5.4 Segment Mass

Regressions equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the segment volume. Segment mass was calculated by assuming the density of the human flesh was homogeneous; a density value of 1 g/cm^3 was used. With a value of unity for the density, the mass values are numerically equal to their corresponding volume values.

E.5.5 Segment Moments of Inertia

Regression equations from the McConville et al. (1980) and Young et al. (1983) studies were used to compute the moments of inertia. The moments of inertia presented are those about the principal axes Xp, Yp, and Zp.

E.5.6 References

McConville, J.T., Churchill, T.D., Kaleps, I., Cuzzi, J., (1980). Anthropometric relationships of body and body segment moments of inertia. AFAMRL-TR-80-119, Wright-Patterson Air Force Base, Ohio.

Young, J.W., Chandler, R.F., Snow, C.C., Robinette, K.M., Zenner, G.F., Lofberg, M.S. (1983). Anthropometrics and mass distribution characteristics of the adult female. FAA-AM-83-16, Revised Edition, FAA Civil Aeromedical Institute, Oklahoma City, Oklahoma.

Table E.5-1—Whole Body Mass, Unsuited

Unsuited Crewmember Body Mass (kg, (lb))	
Minimum	42.64 (94)
Maximum	110.22 (243)
Data are projected to 2015	

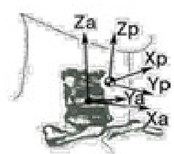
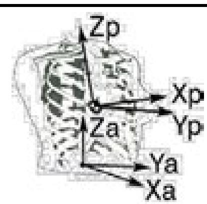
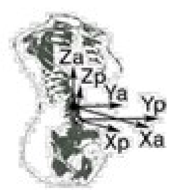
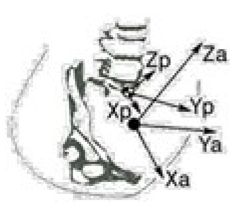
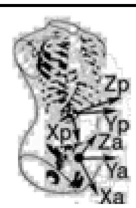
Table E.5-2—Body Segment Mass of a Crewmember, Unsuited

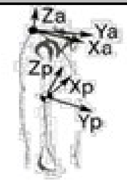
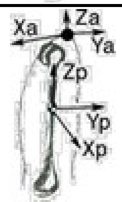
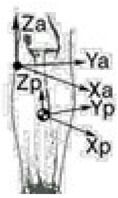
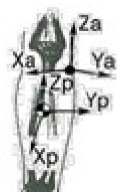
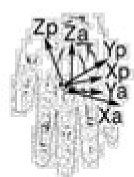
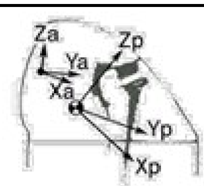
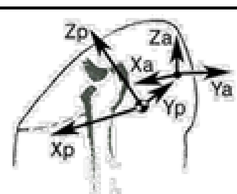
Segment	Mass (kg, (lb))	
	Minimum	**Maximum**
Head (1)	2.99 (6.59)	5.03 (11.08)
Neck (2)	0.49 (1.08)	1.39 (3.07)
Thorax (3)	11.35 (25.02)	34.33 (75.69)
Abdomen (4)	2.14 (4.72)	3.25 (7.16)
Pelvis (5)	5.62 (12.40)	16.46 (36.29)
Upper Arm (6)	0.91 (2.00)	2.74 (6.04)
Forearm (7)	0.59 (1.29)	1.86 (4.09)
Hand (8)	0.24 (0.52)	0.66 (1.45)
Hip Flap (9)	2.22 (4.90)	4.79 (10.55)
Thigh minus Hip Flap (10)	3.86 (8.12)	8.48 (18.69)
Calf (11)	1.94 (4.28)	5.11 (11.27)
Foot (12)	0.44 (0.98)	1.26 (2.77)
Torso (5 + 4 + 3)	19.11 (42.13)	54.05 (119.15)
Thigh (9 + 10)	5.91 (13.03)	13.26 (29.24)
Forearm Plus Hand (7 + 8)	0.82 (1.81)	2.51 (5.54)
Data are projected forward to 2015.		

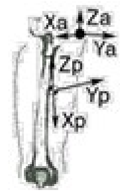
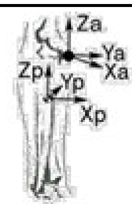
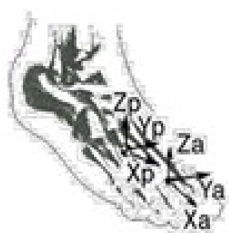
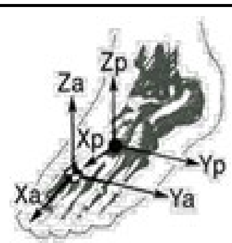
Table E.5-3—Whole Body Center of Mass Location

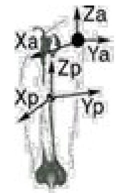
Dimension	Min (cm, (in))	Max (cm, (in))
L (Xa)	-15.27 (-6.01)	-6.40 (-2.52)
L (Ya)	-1.22 (-0.48)	0.97 (0.38)
L (Za)	-3.81 (-1.50)	8.15 (3.21)

Table E.5-4—Body-Segment Center of Mass Location of the Crewmember, Unsuited

Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
Head		Xa	-2.44 (-0.96)	0.53 (0.21)
		Ya	-0.61 (-0.24)	0.61 (0.24)
		Za	2.24 (0.88)	4.04 (1.59)
Neck		Xa	3.40 (1.34)	7.32 (2.88)
		Ya	-0.56 (-0.22)	0.58 (0.23)
		Za	2.92 (1.15)	6.05 (2.38)
Thorax		Xa	3.76 (1.48)	7.06 (2.78)
		Ya	-0.81 (-0.32)	0.48 (0.19)
		Za	13.44 (5.29)	21.97 (8.65)
Abdomen		Xa	-1.47 (-0.58)	1.55 (0.61)
		Ya	-1.65 (-0.65)	2.26 (0.89)
		Za	-4.85 (-1.91)	-1.14 (-0.45)
Pelvis		Xa	-12.17 (-4.79)	-6.96 (-2.74)
		Ya	-1.32 (-0.52)	0.74 (0.29)
		Za	-0.76 (-0.30)	5.18 (2.04)
Torso		Xa	-10.41 (-4.1)	2.49 (0.98)
		Ya	-1.52 (-0.60)	1.73 (0.68)
		Za	16.33 (6.43)	25.60 (10.08)

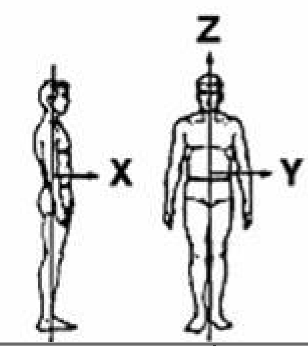
Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
Right upper arm		Xa	-0.71 (-0.28)	-0.91 (-0.36)
		Ya	1.85 (0.73)	-2.29 (-0.90)
		Za	-18.59 (-7.32)	-14.27 (-5.62)
Left upper arm		Xa	-0.64 (-0.25)	2.59 (1.02)
		Ya	-3.68 (-1.45)	-1.80 (-0.71)
		Za	-18.72 (-7.37)	-14.33 (-5.64)
Right forearm		Xa	1.02 (0.40)	0.08 (0.03)
		Ya	-2.11 (-0.83)	4.14 (1.63)
		Za	-9.86 (-3.88)	-8.86 (-3.49)
Left forearm		Xa	1.17 (0.46)	0.13 (0.05)
		Ya	-0.23 (-0.09)	-2.44 (-0.96)
		Za	-9.86 (-3.88)	-9.07 (-3.57)
Right hand		Xa	-0.53 (-0.21)	0.03 (0.01)
		Ya	0.43 (0.17)	0.13 (0.05)
		Za	0.71 (0.28)	1.93 (0.76)
Left hand		Xa	-0.71 (-0.28)	-0.23 (-0.09)
		Ya	-1.35 (-0.53)	0.89 (0.35)
		Za	0.84 (0.33)	2.03 (0.80)
Right hip flap		Xa	-7.77 (-3.06)	1.70 (0.67)
		Ya	5.66 (2.23)	7.37 (2.90)
		Za	-6.73 (-2.65)	-6.05 (-2.38)
Left hip flap		Xa	-8.20 (-3.23)	2.41 (0.95)
		Ya	-10.67 (-4.2)	-5.18 (-2.04)
		Za	-6.96 (-2.74)	-6.20 (-2.44)

Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
Right thigh minus flap		Xa	-3.28 (-1.29)	2.36 (0.93)
		Ya	5.18 (2.04)	8.38 (3.30)
		Za	-24.84 (-9.78)	-23.34 (-9.19)
Left thigh minus flap		Xa	3.10 (1.22)	2.21 (0.87)
		Ya	-9.60 (-3.78)	-5.28 (-2.08)
		Za	-24.87 (-9.79)	-23.62 (-9.30)
Right calf		Xa	-4.24 (-1.67)	-0.10 (-0.04)
		Ya	-6.38 (-2.51)	-4.85 (-1.91)
		Za	-16.18 (-6.37)	-12.01 (-4.73)
Left calf		Xa	-4.34 (-1.71)	0.69 (0.27)
		Ya	4.04 (1.59)	6.83 (2.69)
		Za	-16.00 (-6.30)	-12.32 (-4.85)
Right foot		Xa	-8.51 (-3.35)	-6.63 (-2.61)
		Ya	-0.28 (-0.11)	0.43 (0.17)
		Za	0.46 (0.18)	-0.05 (-0.02)
Left foot		Xa	-8.71 (-3.43)	-6.48 (-2.55)
		Ya	-0.86 (-0.34)	0.89 (0.35)
		Za	0.33 (0.13)	-0.10 (-0.04)
Right thigh		Xa	-4.88 (-1.92)	2.11 (0.83)
		Ya	5.64 (2.22)	8.00 (3.15)
		Za	-17.55 (-6.91)	-17.55 (-6.91)

Segment		Anatomical Axis	Min (cm, (in))	Max (cm, (in))
Left thigh		Xa	-4.75 (-1.87)	2.29 (0.90)
		Ya	-9.65 (-3.80)	-5.26 (-2.07)
		Za	-17.91 (-7.05)	-17.83 (-7.02)
Right forearm plus hand		Xa	0.43 (0.17)	-0.36 (-0.14)
		Ya	-2.29 (-0.90)	4.52 (1.78)
		Za	-15.54 (-6.12)	-14.99 (-5.9)
Left forearm plus hand		Xa	0.43 (0.17)	0
		Ya	0.79 (0.31)	-2.82 (-1.11)
		Za	-15.37 (-6.05)	15.01 (-5.91)

Note: These values are only applicable if the subject is exactly in the anatomical neutral position.

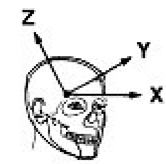
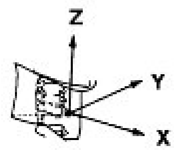
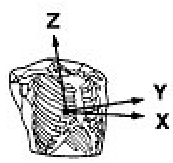
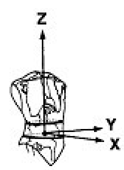
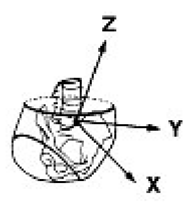
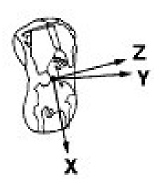
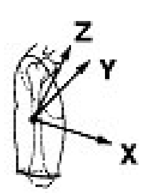
Table E.5-5—Whole Body Moment of Inertia of the Crewmember, Unsuited

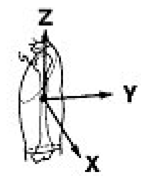
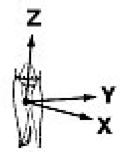
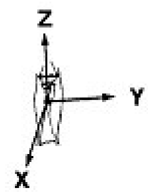
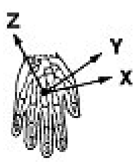
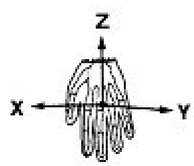
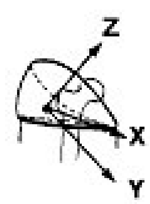
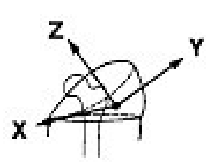


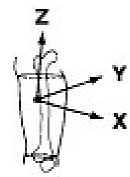
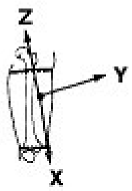
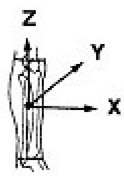
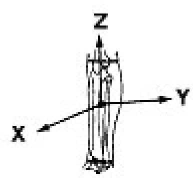
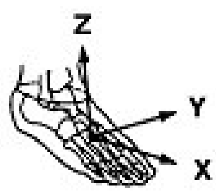
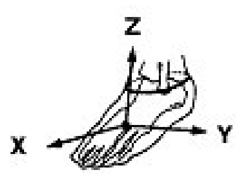
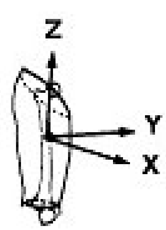
Axis	Min (kg·m2, (lb·ft2))	Max (kg·m2, (lb·ft2))
Xp	6.59 (156.38)	17.69 (419.79)
Yp	6.12 (145.23)	16.43 (389.89)
Zp	0.73 (17.32)	2.05 (48.65)

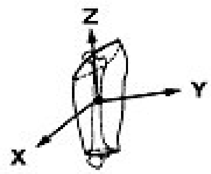
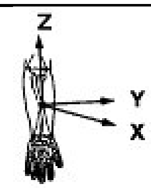
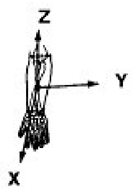
Note: The axes in the figure above represent the principal axes. These values are only applicable if the subject is exactly in the anatomical neutral position.

Table E.5-6—Body-Segment Moment of Inertia of the Crewmember, Unsuited

Segment		Axis	Min (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))	Max (kg·m^2 x10^{-3} (lb·ft^{2}x10^{-3}))
Head		Xp	15 (351)	22 (512)
		Yp	18 (424)	25 (587)
		Zp	14 (322)	16 (379)
Neck		Xp	0.7 (17)	2.2 (53)
		Yp	1.0 (23)	2.7 (64)
		Zp	1.1 (25)	3.4 (81)
Thorax		Xp	183 (4,346)	680 (16,134)
		Yp	135 (3,206)	505 (11,984)
		Zp	119 (2,833)	431 (10,236)
Abdomen		Xp	15 (347)	23 (540)
		Yp	10 (241)	13 (309)
		Zp	21 (500)	35 (826)
Pelvis		Xp	46 (1,092)	148 (3,514)
		Yp	34 (810)	137 (3,258)
		Zp	61 (1,440)	173 (4,104)
Torso		Xp	638 (15,143)	2,030 (48,178)
		Yp	577 (13,702)	1840 (43,654)
		Zp	205 (4,865)	644 (15,273)
Right upper arm		Xp	5.4 (129)	18 (430)
		Yp	5.6 (133)	19 (462)
		Zp	1.0 (24)	3.9 (92)

Segment		Axis	Min ($kg \cdot m^2 x10^{-3}$ ($lb \cdot ft^2 x10^{-3}$))	Max ($kg \cdot m^2$ $x10^{-3}$ ($lb \cdot ft^2 x10^{-3}$))
Left upper arm		Xp	5.3 (126)	17.7 (420)
		Yp	5.5 (130)	19 (449)
		Zp	0.9 (22)	3.8 (89)
Right forearm		Xp	2.8 (67)	12 (276)
		Yp	2.7 (65)	12 (282)
		Zp	0.5 (11)	1.8 (43)
Left forearm		Xp	2.8 (66)	11 (257)
		Yp	2.7 (63)	11 (265)
		Zp	0.5 (11)	1.6 (39)
Right hand		Xp	0.6 (14)	1.6 (38)
		Yp	0.5 (11)	1.3 (31)
		Zp	0.2 (4)	0.5 (13)
Left hand		Xp	0.6 (15)	1.6 (37)
		Yp	0.5 (13)	1.3 (31)
		Zp	0.2 (4)	0.5 (12)
Right hip flap		Xp	8.1 (191)	17 (412)
		Yp	10 (246)	22 (530)
		Zp	13 (318)	29 (696)
Left hip flap		Xp	7.9 (188)	17 (398)
		Yp	11 (255)	22 (519)
		Zp	14 (324)	28 (671)

Segment		Axis	Min ($kg \cdot m^2 x10^{-3}$ ($lb \cdot ft^2 x10^{-3}$))	Max ($kg \cdot m^2$ $x10^{-3}$ ($lb \cdot ft^2 x10^{-3}$))
Right thigh minus flap		Xp	34 (800)	79 (1,885)
		Yp	33 (785)	82 (1,941)
		Zp	14 (327)	32 (753)
Left thigh minus flap		Xp	34 (798)	75 (1,784)
		Yp	33 (789)	79 (1,878)
		Zp	13 (317)	31 (729)
Right calf		Xp	26 (615)	75 (1,790)
		Yp	26 (613)	76 (1,815)
		Zp	3.1 (73)	8.9 (210)
Left calf		Xp	26 (614)	77 (1,826)
		Yp	26 (615)	78 (1,855)
		Zp	3.0 (70)	9.1 (215)
Right foot		Xp	0.4 (9)	1.0 (24)
		Yp	1.6 (37)	5.5 (130)
		Zp	1.6 (39)	5.8 (138)
Left foot		Xp	0.4 (9)	1.0 (24)
		Yp	1.6 (39)	5.4 (127)
		Zp	1.7 (41)	5.7 (134)
Right thigh		Xp	85 (2,009)	208 (4,940)
		Yp	87 (2,063)	220 (5,215)
		Zp	27 (651)	59 (1,401)

Segment		Axis	Min (kg·m^{2}x10^{-3} (lb·ft^{2}x10^{-3}))	Max (kg·m^2 x10^{-3} (lb·ft^{2}x10^{-3}))
Left thigh		Xp	85 (2,022)	200 (4,757)
		Yp	88 (2,088)	212 (5,024)
		Zp	27 (649)	57 (1,350)
Right forearm plus hand		Xp	11 (262)	40 (939)
		Yp	11 (257)	39 (935)
		Zp	0.7 (16)	2.4 (58)
Left forearm plus hand		Xp	11 (260)	37 (887)
		Yp	11 (256)	37 (881)
		Zp	0.6 (15)	2.2 (53)

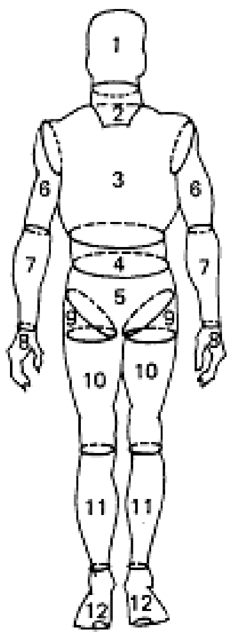
Note: The axes in the figure above represent the principal axes. These values are only applicable if the subject is exactly in the anatomical neutral position.

E.6 BODY VOLUME

Table E.6-1—Whole-Body Volume of Crewmember

Crewmember Body Volume (cm^3 [in.^{3}])	
Minimum	46,431 (2,833)
Maximum	113,556 (6,930)

Table E.6-2—Body-Segment Volume of Crewmember



Segment	Volume (cm^3 [$in.^3$])	
	Minimum	Maximum
1 Head	3,692 (225)	4,607 (281)
2 Neck	575 (35)	1,455 (89)
3 Thorax	12,515(764)	36,034 (2,199)
4 Abdomen	1,104 (67)	3,562 (217)
5 Pelvis	4,961 (303)	17,469 (1,066)
6 Upper Arm*	957 (58)	2,901 (177)
7 Forearm*	643(39)	1,920(117)
8 Hand*	285 (17)	637 (39)
9 Hip Flap	2,510 (153)	5,191 (317)
10 Thigh minus Flap*	4,041 (247)	8,399 (513)
11 Calf*	2,195 (134)	5,062 (309)
12 Foot*	518 (32)	1,235 (75)
Torso (3 + 4 + 5)	19,269 (1,176)	57,498 (3,509)
Thigh (9 + 10)	6,571 (401)	13,424 (819)
Forearm plus Hand (7 + 8)*	930 (57)	2,556 (156)

**The minimum and maximum values for these segments were derived from the calculated average between the left and right segment values.*

E.7 CREWMEMBER STRENGTH

Strength refers to a person's ability to generate force. Applying the following strength requirements will result in a minimum and maximum applied crew load to be used for operational and hardware design. The minimum load pertains to operational strength that accommodates the weakest person while the maximum load represents the force the hardware must be able to withstand without failure. It is important to note that these requirements apply to intentional forces applied by the crewmember. Durability is applicable to structural integrity of hardware due to non-intentional crew forces which is handled through the structural design process.

Tables E.7-(1-6) provide both minimum (operational) and maximum (withstand) strength capabilities for unsuited, suited unpressurized, and suited pressurized conditions.

E.7.1 Withstand (Maximum Strength) Crew Loads

Vehicle components and equipment are to be designed to withstand large forces exerted by a strong crewmember during nominal hardware operation, without breaking or sustaining damage that would deem the hardware inoperable. Humans may also exert high forces when operating controls in emergency situations, such as attempting to open a hatch for emergency egress. The resulting possible damage to equipment could make it impossible to respond safely to the emergency. To avoid overdesign, a task analysis is performed to identify which interfaces must tolerate maximum crew loads. This includes identifying critical hardware that may be inadvertently used as a mobility aid or restraint. Identified crew interfaces must withstand the value provided in the corresponding "withstand crew loads" column, which provides the maximum loads that crew can be expected to exert. The data provided in the tables are for unsuited, suited-unpressurized, and suited-pressurized conditions. Data was derived from a collection of journal articles associated with human strength data.

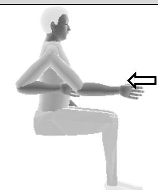
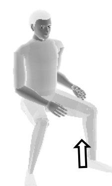
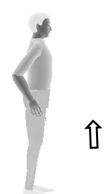
E.7.2 Crew Operational Loads (for Minimum Strength)

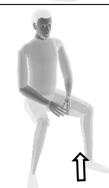
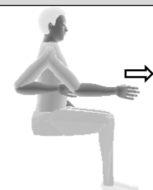
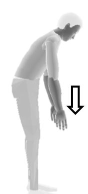
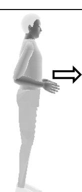
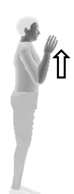
The design must allow for all crewmembers to perform any of the requested tasks efficiently and effectively, thus ensuring task and/or mission success. A human-centered design process is to be used when implementing operational strength limits. Analysis of expected crew operations, activities, and tasks is to drive the design of human-machine interfaces. The analysis should evaluate and define activities/tasks in terms of criticality and required postures. Identified crew interfaces must be actuated and operable at the value provided in the corresponding "Crew Operational Loads" columns, which provide the maximum load that the weakest crewmember could be expected to exert. The data provided in the tables are for unsuited, suited-unpressurized, and suited-pressurized conditions. Data was derived from a collection of journal articles associated with human strength data.

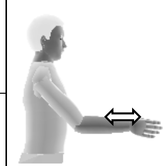
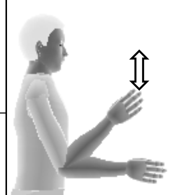
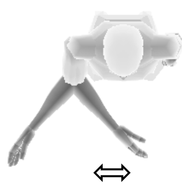
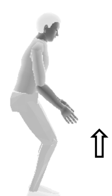
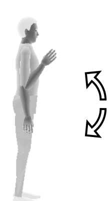
For this purpose, tasks that involve the possibility of a single failure causing loss of life or vehicle have a definition of Criticality 1 Operations in the following tables. Tasks involving Loss of Mission (LOM) alone have a definition of Criticality 2 Operations. The values in the criticality 1 and 2 columns also include decrement factor(s) to reflect the deconditioning effects on crewmembers after an extended duration of mission. All other tasks fall into the "Other Operations" category, and do not have deconditioning or a factor of safety applied over minimal anticipated crew strength. It is important to note that the designer should be careful not to implement multiple safety factors. For example, NASA-STD-5017 torque/force margin requirements (4.10.0) levy an extra safety factor on the applied torque/force to a given mechanism. Implementing this requirement along with the already built-in safety factor (i.e., criticality) in the strength tables results in an overly conservative design.

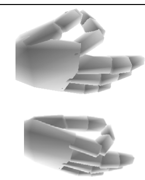
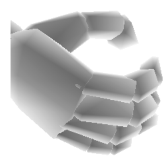
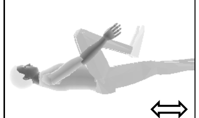
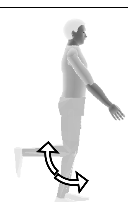
Data was derived from a collection of journal articles associated with human strength data. In addition, other references were used, such as the MIL-STD-1472F and the Occupational and Biomechanics textbook (Chaffin, D. B., Occupation Biomechanics, Second Edition, John Wiley & Sons, Inc., 1991), to set a standard for very specific strength data such as lifting strength.

Table E.7-1—Crew Operational Loads, Unsuited

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
One Handed Pulls						
Seated Horizontal Pull In[2]	Subject in a seated position pulls towards his/her body. Unilateral/Isometric measurement		111 (25)	147 (33)	276 (62)	449 (101)
Seated Vertical Pull Down[2]	Subject in a seated position pulls downwards. Unilateral/Isometric measurement		125 (28)	165 (37)	311 (70)	587 (132)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap		49 (11)	67 (15)	125 (28)	756 (170)
Standing Vertical Pull Up2	Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side		53 (12)	71 (16)	133 (30)	725 (163)
Two Handed Pulls						
Standing Vertical Pull Down [2]	Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward		138 (31)	182 (41)	343 (77)	707 (159)
Standing Pull in[2]	Standing erect with feet apart, with both hands holding handle located in front, pulling inward towards body		58 (13)	80 (18)	147 (33)	391 (88)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Standing Vertical Pull Up[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward		89 (20)	116 (26)	218 (49)	1437 (323)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders		93 (21)	125 (28)	236 (53)	1188 (267)
One Handed Push						
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		89 (20)	116 (26)	218 (49)	436 (98)
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		67 (15)	85 (19)	160 (36)	280 (63)
Two Handed Push						
Standing Vertical Push Down[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards		102 (23)	133 (30)	254 (57)	525 (118)
Standing Horizontal Push Out1	Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body		62 (14)	85 (19)	165 (37)	596 (134)
Standing Vertical Push Up2	Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders		76 (17)	98 (22)	187 (42)	1094 (246)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Arms						
Arm Pull[2]	Subject pulls handle forward and backward		44 (10)	58 (13)	107 24)	249 (56)
Arm Push[2]	Subject pushes handle forward and backward		40 (9)	53 (12)	98 (22)	222 (50)
Arm Up[2]	Subject pushes and pulls handle in various directions as shown by the figures		18 (4)	22 (5)	40 (9)	107 (24)
Arm Down[2]	Subject pushes and pulls handle in various directions as shown by the figures		22 (5)	31 (7)	58 (13)	116 (26)
Arm In[2]	Subject moves handle medially		22 (5)	31 (7)	58 (13)	98 (22)
Arm Out2	Subject moves handle laterally		13 (3)	18 (4)	36 (8)	76 (17)
Lifting						
Lifting Strength[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms, shoulders, and legs		36 (8)	49 (11)	93 (21)	1228 (276)
Elbow						
Flexion[2]	Subject moves forearm in a sagittal plane around the elbow joint		13 (3)	18 (4)	36 (8)	347 (78)
Extension[2]	Subject moves forearm in a sagittal plane around the elbow joint		27 (6)	36 (8)	67 (15)	249 (56)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Wrist & Hand						
Wrist Flexion[2]	Subject bends wrist in a palmar direction		31 (7)	40 (9)	76 (17)	209 (47)
Wrist Extension[2]	Subject bends the wrist in a dorsal direction		13 (3)	18 (4)	36 (8)	85 (19)
Pinch[1]	Subject squeezes together the thumb and finger		9 (2)	13 (3)	18 (4)	200 (45)
Grasp[1]	Subject maintains an eccentric tight hold of an object		347 (78)	463 (104)	694 (156)	1219 (274)
Grip[1]	Subject maintains a concentric tight hold of an object		49 (11)	67 (15)	102 (23)	783 (176)
Leg						
Hip Flexion[2]	Subject moves leg in the sagittal plane around the hip joint toward the front of the body		116 (26)	156 (35)	289 (65)	645 (145)
Hip Extension[2]	Subject moves upper and lower leg in a sagittal plane around the hip joint		191 (43)	254 (57)	476 (107)	658 (148)
Leg Press[1]	Subject moves leg in a sagittal plane around the hip joint toward the back of the body		618 (139)	827 (186)	1552 (349)	2584 (581)
Knee Flexion[1]	Subject moves lower leg in a sagittal plane around the knee joint		53 (12)	71 (16)	138 (31)	325 (73)
Knee Extension[1]	Subject moves lower leg in a sagittal plane around the knee joint		142 (32)	191 (43)	383 (86)	783 (176)

[1] *Post spaceflight maximal measured strength decrement.*
[2] *Post spaceflight estimated strength decrement. Range is 0%-26%. Average estimated is 20%. Based on max EDOMP Data. Not all motions were measured on EDOMP.*

Table E.7-2—Torque Values for Pronation and Supination, Unsuited

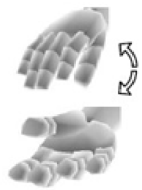
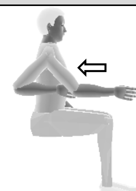
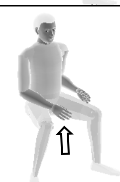
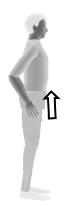
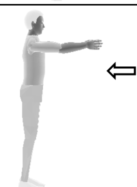
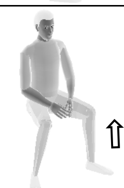
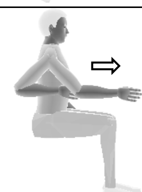
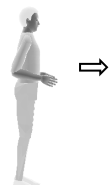
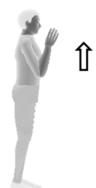
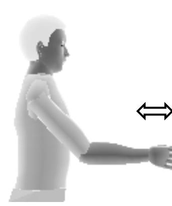
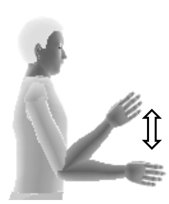
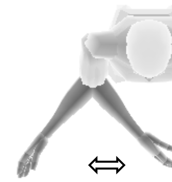
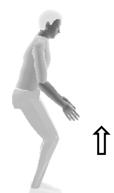
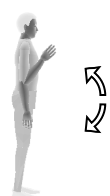
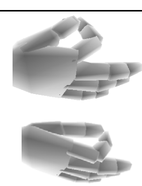
Type of Strength			Crew Operational Loads (N-m, (in-lb))			Withstand Crew Loads (N-m, (in-lb))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Pronation[2]	Subject rotates hands and forearms medially		0.8 (7.4)	1.1 (10)	2.1 (18.4)	11.3 (100)
Supination[2]	Subject rotates hands and forearms laterally		0.8 (7.4)	1.1 (10)	2.1 (8.4)	11.3 (100)

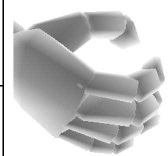
Table E.7-3—Crew Loads, Unpressurized Suited

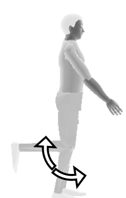
Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
One Handed Pulls						
Seated Horizontal Pull In[2]	Subject in a seated position pulls towards his/her body. Unilateral/Isometric measurement		78 (18)	103 (23)	193 (43)	314 (71)
Seated Vertical Pull Down[2]	Subject in a seated position pulls downwards. Unilateral/Isometric measurement		88 (20)	116 (26)	218 (49)	411 (92)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap		34 (8)	47 (11)	88 (20)	529 (119)
Standing Vertical Pull Up[2]	Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side		37 (8)	50 (11)	93 (21)	508 (114)

Type of Strength			**Crew Operational Loads (N, (lbf))**			**Withstand Crew Loads (N, (lbf))**
			Crit 1 Ops	**Crit 2 Ops**	**Other Ops**	
Standing Vertical Pull Down[2]	Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward		97 (22)	127 (29)	240 (54)	495 (111)
Standing Pull in[2]	Standing erect with feet apart, with both hands holding handle located in front, pulling inward towards body		41 (9)	56 (13)	103 (23)	274 (62)
Standing Vertical Pull Up[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward		62 (14)	81 (18)	153 (34)	1006 (226)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders		65 (15)	88 (20)	165 (37)	832 (187)
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		62 (14)	81 (18)	153 (34)	305 (69)
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		47 (11)	60 (13)	112 (25)	196 (44)

Type of Strength			**Crew Operational Loads (N, (lbf))**			**Withstand Crew Loads (N, (lbf))**
			Crit 1 Ops	**Crit 2 Ops**	**Other Ops**	
Type of Strength			**Crew Operational Loads (N, (lbf))**			**Withstand Crew Loads (N, (lbf))**
			Crit 1 Ops	**Crit 2 Ops**	**Other Ops**	
Two Handed Push						
Standing Vertical Push Down[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards		71 (16)	93 (21)	178 (40)	368 (83)
Standing Horizontal Push Out[1]	Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body		43 (10)	60 (13)	116 (26)	417 (94)
Standing Vertical Push Up[2]	Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders		53 (12)	69 (15)	131 (29)	766 (172)
Arms						
Arm Pull[2]	Subject pulls handle forward and backward		31 (7)	41 (9)	75 (17)	174 (39)
Arm Push[2]	Subject pushes handle forward and backward		28 (6)	37 (8)	69 (15)	155 (35)
Arm Up[2]	Subject moves handle up		13 (3)	15 (4)	28 (6)	75 (17)
Arm Down[2]	Subject moves handle down		15 (4)	22 (5)	41 (9)	81 (18)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Arm In[2]	Subject moves handle medially		15 (4)	22 (5)	41 (9)	69 (15)
Arm Out[2]	Subject moves handle laterally		9 (2)	13 (3)	25 (6)	53 (12)
Type of Strength			**Crew Operational Loads (N, (lbf))**			**Withstand Crew Loads (N, (lbf))**
			Crit 1 Ops	**Crit 2 Ops**	**Other Ops**	
Lifting						
Lifting Strength[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms and shoulders, and legs		25 (6)	34 (8)	65 (15)	860 (193)
Elbow						
Flexion[2,3]	Subject moves forearm in a sagittal plane around the elbow joint		9 (2)	13 (3)	25 (6)	243 (55)
Extension[2,3]	Subject moves forearm in a sagittal plane around the elbow joint		19 (4)	25 (6)	47 (11)	174 (39)
Wrist & Hand						
Wrist Flexion[2,3]	Subject bends wrist in a palmar direction		22 (5)	28 (6)	53 (12)	146 (33)
Wrist Extension[2,3]	Subject bends the wrist in a dorsal direction		9 (2)	13 (3)	25 (6)	60 (13)
Pinch [1]	Subject squeezes together the thumb and finger		14 (3)	20 (5)	27 (6)	300 (68)

Type of Strength			Crew Operational Loads (N, (lbf))			Withstand Crew Loads (N, (lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Grasp[1,3]	Subject maintains an eccentric tight hold of an object		243 (55)	324 (73)	486 (109)	853 (192)
Grip[1]	Subject maintains a concentric tight hold of an object		25 (6)	34 (8)	51 (12)	392 (88)

Legs						
Hip Flexion[2,3]	Subject moves leg in the sagittal plane around the hip joint toward the front of the body		81 (18)	109 (25)	202 (46)	452 (102)
Knee Flexion[1,3]	Subject moves lower leg in a sagittal plane around the knee joint, decreasing the angle between the upper and lower leg		37 (8)	50 (11)	97 (22)	228 (51)
Knee Extension[1,3]	Subject moves lower leg in a sagittal plane around the knee joint, increasing the angle between the upper and lower leg		99 (22)	134 (30)	268 (60)	548 (123)

1. Post spaceflight maximal measured strength decrement.
2. Post spaceflight estimated strength decrement. Range is 0%-47%. Average estimated is 33%. Based on CRV Requirements Document.
3. Suit decrement not measured directly, but estimated based on functional strength testing of other movements

Table E.7-4—Torque Values Pronation and Supination, Unpressurized Suited

Type of Strength			Crew Operational Loads (N-m, (in-lb))			Withstand Crew Loads (N-m, (in-lb))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Pronation[2]	Subject rotates hands and forearms medially		0.7 (6.4)	0.9 (8.5)	1.8 (16)	13.1 (116)

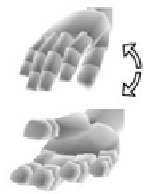
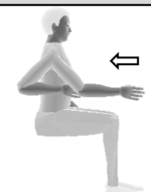
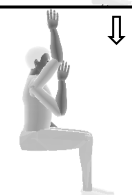
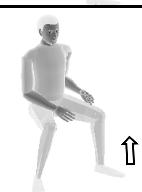
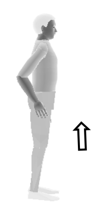
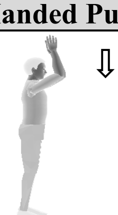
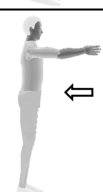
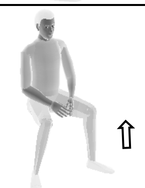
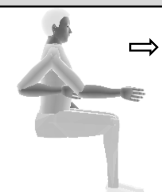
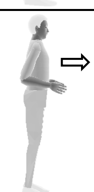
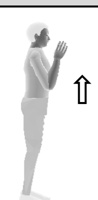
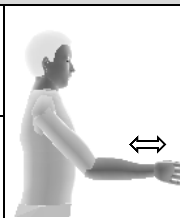
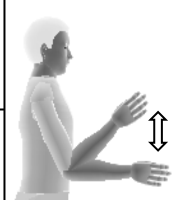
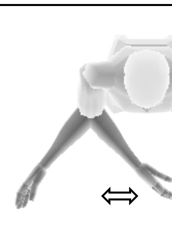
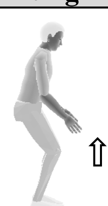
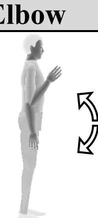
Type of Strength			Crew Operational Loads (N-m, (in-lb))			Withstand Crew Loads (N-m, (in-lb))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Supination[2]	Subject rotates hands and forearms laterally		0.7 (6.4)	0.9 (8.5)	1.8 (16)	13.1 (116)

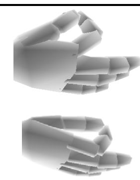
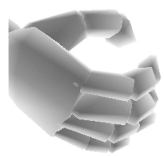
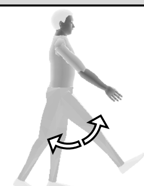
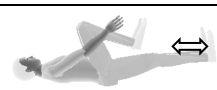
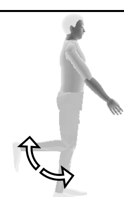
Table E.7-5—Crew Loads, Pressurized Suited

(Only for an EVA type suit and not for a launch and entry type suit, due to extreme difficulty of the LEA suit to operate under pressurized condition)

Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
One Handed Pulls						
Seated Horizontal Pull In[2]	Subject in a seated position pulls towards his/her body. Unilateral/ Isometric measurement		56 (13)	74 (17)	138 (31)	225 (51)
Seated Vertical Pull Down[2]	Subject in a seated position pulls downwards. Unilateral/Isometric measurement		63 (14)	83 (19)	156 (35)	294 (66)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, dominant hand grasping D-ring located directly to the front above the floor, pulling upward while keeping shoulder squares & other arm in lap		25 (6)	34 (8)	63 (14)	378 (85)
Standing Vertical Pull Up[2]	Standing erect with feet apart, dominant hand grasping underside of D-ring located directly to the side above standing surface, pulling upward while keeping shoulders square and other arm relaxed at side		27 (6)	36 (8)	67 (15)	363 (82)
Two Handed Pulls						
Standing Vertical Pull Down [2]	Standing erect with feet apart, with both hands holding handle located above shoulders, pulling downward		69 (16)	91 (21)	172 (39)	354 (80)
Standing Pull In[2]	Standing erect with feet apart, with both hands holding handle located in front, pulling inward towards body		29 (7)	40 (9)	74 (17)	196 (44)

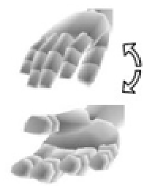
Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Standing Vertical Pull Up[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward		45 (10)	58 (13)	109 (25)	719 (162)
Seated Vertical Pull Up[2]	Sitting erect with feet apart, grasping both sides of handle located directly to the front above the floor, pulling upward using arms and shoulders		47 (11)	63 (14)	118 (27)	594 (134)
One Handed Push						
Seated Horizontal Push Out[2]	Subject in a seated position pushing away from his/her body. Unilateral/Isometric measurement		45 (10)	58 (13)	109 (25)	218 (49)
Seated Vertical Push Up[2]	Subject in a seated position pushing upward in a vertical direction. Unilateral/Isometric measurement		34 (8)	43 (10)	80 (18)	140 (32)
Two Handed Push						
Standing Vertical Push Down[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pushing downwards		51 (12)	67 (15)	127 (29)	263 (59)
Standing Horizontal Push Out[1]	Standing erect with feet apart, with both hands holding handle located in front, pushing out away from body		31 (7)	43 (10)	83 (19)	298 (67)
Two Handed Push						
Standing Vertical Push Up[2]	Standing erect with feet apart, grasping from below, both sides of handle located directly in front above standing surface. Pushing upwards using arms and shoulders		38 (9)	49 (11)	94 (21)	547 (123)

Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Arm						
Arm Pull[2]	Subject pulls handle forward and backward		22 (5)	29 (7)	54 (12)	125 (28)
Arm Push[2]	Subject pushes handle forward and backward		20 (5)	27 (6)	49 (11)	111 (25)
Arm Up[2]	Subject moves handle up		9 (2)	11 (3)	20 (5)	54 (12)
Arm Down[2]	Subject moves handle down		11 (3)	16 (4)	29 (7)	58 (13)
Arm In[2]	Subject moves handle medially		11 (3)	16 (4)	29 (7)	49 (11)
Arm Out[2]	Subject moves handle laterally		7 (2)	9 (2)	18 (4)	38 (9)
Lifting						
Lifting Strength[2]	Standing with feet apart with a slight bend at the knees and waist, grasping a handle with both hands located directly in front and pulling upward using primarily arms and shoulders, and legs		18 (4)	25 (6)	47 (11)	614 (138)
Elbow						
Flexion[2, 3]	Subject moves forearm in a sagittal plane around the elbow joint		7 (2)	9 (2)	18 (4)	174 (39)
Extension[2, 3]	Subject moves forearm in a sagittal plane around the elbow joint		14 (3)	18 (4)	34 (8)	125 (28)
Wrist & Hand						
Wrist Flexion[2, 3]	Subject bends wrist in a palmar direction		19 (4)	25 (6)	37 (8)	101 (23)

Type of Strength			Crew Operational Loads (N(lbf))			Withstand Crew Loads (N(lbf))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Wrist Extension[2,3]	Subject bends the wrist in a dorsal direction		7 (2)	9 (2)	14 (3)	33 (7)
Pinch [1]	Subject squeezes together the thumb and finger		14 (3)	20 (5)	27 (6)	300 (68)
Grasp[1,3]	Subject maintains an eccentric tight hold of an object		174 (39)	232 (52)	347 (78)	610 (137)
Grip[1]	Subject maintains a concentric tight hold of an object		25 (6)	34 (8)	51 (12)	392 (88)
Leg						
Hip Flexion[2,3]	Subject moves leg in the sagittal plane around the hip joint toward the front of the body		58 (13)	78 (18)	145 (33)	323 (73)
Hip Extension[2,3]	Subject moves leg in a sagittal plane around the hip joint toward the back of the body		96 (22)	127 (29)	238 (54)	329 (74)
Leg Press[1,3]	Subject pushes a weight away from them using their legs		309 (70)	414 (93)	776 (175)	1292 (291)
Knee Flexion[1,3]	Subject moves lower leg in a sagittal plane around the knee joint		27 (6)	36 (8)	69 (16)	163 (37)
Knee Extension[1]	Subject moves lower leg in a sagittal plane around the knee joint		71 (16)	96 (22)	192 (43)	392 (88)

1. Post spaceflight maximal measured strength decrement.
2. Post spaceflight estimated strength decrement. Range is 0%-47%. Average estimated is 33%. Based on CRV Requirements Document.
3. Suit decrement not measured directly, but estimated based on functional strength testing of other movements

Table E.7-6—Torque Values Pronation and Supination, Pressurized Suited

Type of Strength			Crew Operational Loads (N○m, (in○lb))			Withstand Crew Loads (N○m, (in○lb))
			Crit 1 Ops	Crit 2 Ops	Other Ops	
Pronation[2]	Subject rotates hands and forearms medially		0.9 (8)	1.2 (11)	2.3 (20)	13 (115)
Supination[2]	Subject rotates hands and forearms laterally		0.9 (8)	1.2 (11)	2.3 (20)	13 (115)

APPENDIX F

DISPLAY STANDARD

F.1 PURPOSE

The purpose of this NASA technical requirement appendix is to provide consistent and uniform technical requirements for the design, selection, and application characteristics and capabilities for the development of displays across spaceflight programs that support operator task performance. Adherence to these technical requirements will improve mission safety by enabling operators to effectively plan for, identify, and take action in response to evolving operating conditions; and maintain the situation awareness, mental resources, and adaptive capacity to make decisions and solve problems. In addition, following these requirements will promote error reduction, ease of learning, and ease of use.

Consistency refers to the level of similarity in visual style and operation within and among different crew interface designs. Systems that have been designed with consistency in mind require less training and feel familiar. The number of different codes and ways of operating are minimized, which reduces cognitive workload and operational errors. Cross-system consistency is achieved by incorporating threads of similarity in key components across designs. Higher levels of consistency across vehicles will decrease the risk of errors and result in a safer spacecraft environment.

A program established Labeling Plan and Icon Library will be a complement to this document. Individual spaceflight programs may also have more detailed design information in their corresponding As-Built Display Framework type of documents.

F.2 SCOPE

The display technical requirement applies to Contractor Furnished Equipment (CFE), Government Furnished Equipment (GFE), and items provided by International Partners for flight elements only (not ground). This technical requirement applies to displays on fixed units, as well as those on portable computers, including laptops and tablets.

Commercial-off-the-Shelf (COTS) applications that provide vehicle insight and commanding shall adhere to the requirements listed in this document. COTS applications that do not provide vehicle insight and commanding shall provide an assessment of compliance in order to perform a risk assessment of the non-compliant items as well as determine what inconsistencies need to be added to crew training.

This technical requirement does not currently apply to Augmented Reality (AR) displays.

This technical requirement is applicable to all programs, including future programs. Spaceflight programs are expected to adopt this display technical requirement instead of developing a separate lower-level document. Any deviations or waivers to the requirements of this document should be coordinated with NASA Standards OCHMO and approved by the Chief Health and Medical Officer Management Board.

This technical requirement is intended to serve two primary audiences: 1) Designers and developers who will use the technical requirements when providing software user interfaces, and 2) Verification teams who will verify delivered software interfaces against these technical requirements.

The convention used in this Display Standard are as follows:

a) "Must" -- Used to indicate a requirement to be implemented and the associated implementation verified. These requirements can be tailored in additional program requirement documents and written as “shall” where needed;
b) "Should" -- Used to indicate a goal that the designer is expected to follow, if possible, but that is not formally verified;
c) "Will" -- Used to indicate a statement of fact and is not verified.

F.3 DOCUMENTS

F.3.1 Reference Documents

The following documents contain supplemental and background information that may be helpful in implementing these technical requirements

Government	
NASA/SP-2010-3407	Human Integration Design Handbook (HIDH)
HF-STD-001	Human Factors Design Standard (HFDS)
NUREG-0700	Human-System Interface Design Review Guidelines
MIL-STD-1472	Department of Defense Design Criteria Standard: Human Engineering

International Electrotechnical Commission (IEC)	
IEC/TC 100	Audio, video and multimedia systems and equipment
IEC/TC 110	Electronic displays

International Organization for Standardization (ISO)	
ISO/IEC JTC 1/SC 29	Coding of audio, picture, multimedia and hypermedia information

F.4 GENERAL

This section covers the crew interfaces through which dynamic information is exchanged between the crew and the system (primarily through controls and displays). Well-designed crew interfaces are critical for crew safety and enabling the crew to learn, anticipate, monitor for, and respond safely and efficiently to that dynamic information. Appropriate consistency across crew interfaces can also minimize training.

Displays may be visual, audible, or haptic. Visual displays deliver information by using visible media to present text, graphics, colors, indicator lights, images, video, animations, and symbols. This information can also be provided on dynamic displays such as control panels.

F.4.1 General

a. The amount of information displayed should be limited to what is needed to perform required tasks or to provide situation awareness necessary to make decisions.
b. A display should provide the information needed to perform the task at hand without requiring the operator to navigate to additional displays.
c. Vertical scrolling should be limited to procedures or lists.
d. Horizontal scrolling should be avoided.
e. Information must be presented in a directly usable form that does not require mental transposition or computation by the operator.
f. Each display within a predefined suite (i.e., set of related GUIs) should have consistency with other formats in the suite regarding the appearance, location, and interact.
g. Modes (e.g., test mode, edit mode) in the interface should be used sparingly because they restrict operator control of the system and can cause frustration and errors.
h. Operator actions that are irreversible (e.g., could result in the loss of data) must be safeguarded via confirmation dialog boxes or the equivalent (i.e., two (2) independent operator actions).

F.4.2 Layout and Appearance

a. Layout of information on a display must support task flow (e.g., left-to-right or top-to-bottom orientation aligned with procedure flow, or located according to architecture).
b. Recurring data fields should be displayed in consistent relative positions across formats.
c. Display elements to be used together should be grouped in close proximity on the screen.
d. A grouping of related characters (e.g., letters, numbers, and symbols) should be visually separated from other groupings, or from graphical or virtual borders.
e. The primary display navigation menu bar must be located at either the top or bottom of each display.
f. All displays must have a common dedicated area for the display of key information to be visible at all times (e.g., time, system messages, alerts, communication status: Loss of Signal / Acquisition Of Signal).
g. Each display must have a unique title in a consistent location that is visible at all times.
h. When more information is available for display than can be shown (e.g., multiple pages, or multiple items in a scrollable list), the system must provide an indication of the portion being viewed, and the total amount of information.

i. Elements that are selectable (e.g., buttons, menu options), elements that are static (e.g., labels), elements for embedded navigation, and elements designed for alphanumeric input (e.g., data entry fields) must be visually distinct from one another.
j. Displays for different modes of operation (e.g., test/sim mode vs. flight/mission mode) must be visually distinct.

F.4.3 Interacting with the Vehicle

F.4.3.1 Telemetry

a. If a display element has states or modes, the current state must be indicated.
b. The capability to show the violation of any operational limit or telemetry threshold of a display element must be provided.
c. There must be an indication when data are stale.
d. A yellow or red up or down arrow following a telemetry value must be used to indicate that telemetry is outside of upper or lower thresholds that trigger a Caution or Warning alarm.
e. The system must provide an indication that a telemetry value is off-scale high or low when that information is necessary to address a malfunction.
f. Telemetry fields should have sufficient fixed placeholder width to show the longest possible value, including the size of any data quality indicators.
g. When text data overflow occurs, each character of the entire field must be replaced by yellow asterisks.
h. When numeric data overflow occurs, each character of the entire field must be replaced by yellow asterisks, except for the signed field and the decimal point.

F.4.3.2 Commanding

a. Commanding should be accomplished via a “Command Popup” (popup menu) to minimize operator memory load and number of actions.
b. Command Popups must contain a unique name, options list, indication of current selection, and indication of the option to be selected.
c. Operator actions that are irreversible (i.e., could result in the loss of data) must be safeguarded via confirmation dialog boxes or the equivalent.
d. The system must require at least 2 independent commands to activate/execute mission critical and safety critical controls.
e. Commands with an arm control must be accompanied by a safe control (that removes the armed condition) located to the right or beneath the arm control.
f. Commands that change vehicle state must provide a positive indication of control activation (e.g., telemetry change, message indicating completed, running, failed, or unknown).
g. Command names for different commands must be distinguishable from one another.
h. If command operations have counterparts, congruent pairs of command names must be used in a consistent vertical order (e.g., on/off, enable/inhibit, yes/no, open/close, high/low, Max/Min, Auto/Man).
i. Commands that are irreversible or hazardous should include a black and yellow diagonally striped border (i.e., hazard tape).

j. Controls that are used to send commands to change vehicle state must be visually distinct from other controls.
k. The display must indicate that a command was accepted by the Flight Software.

F.4.3.3 Status and Error Messages

a. Status and error messages must be displayed in a consistent, designated location.
b. Status and error messages should contain the information necessary for situation awareness, to make a decision, or complete the related action.
c. Error messages should convey what is wrong, what corrective actions can be taken, and what caused the error.
d. Status data should indicate when routine maintenance activity is required.
e. Stored data should be searchable to assist in anomaly resolution.
f. Popup messages should be able to be moved/cleared by crew or cleared automatically.

F.5 DISPLAY COMPONENTS

F.5.1 Text

a. Text should use the American Standard Code for Information Interchange (ASCII) character set.
b. Sans serif font should be used.
c. The font must allow discrimination of similar characters (e.g., letter l/number 1; letter O/number 0).
d. A fixed-width font must be used on numerical and tabular data.
e. A proportional font must be used for content that is narrative, such as electronic crew procedures.
f. The system should provide an optical zoom function that allows an area within the display to be temporarily magnified.
g. Character height must be a minimum of 0.25 deg, with 0.4 deg or greater is preferred. (Note that Font height in degrees refers to the angle subtended at the eye by the height of an upper-case letter in the font. For example: 0.25 deg is 10-point type at 32 in).
h. Non-acronym text must be mixed case (e.g., uppercase and lowercase letters).
i. Acronyms and abbreviations must be as specified in the Operations Nomenclature Plan.

F.5.2 Labels

a. Labels should be shown with data fields.
b. The wording and grammatical structure of labels should be consistent throughout a display.
c. Labels should be shown in horizontal orientation.
d. Data field labels must appear to the left of data values, or above data values when data are in a columnar format.
e. When vertical orientation of the label is necessary, labels must be rotated counter-clockwise, (see Figure F.5-1—Examples of Horizontal Text (Preferred) and Vertical Text).

Horizontal Text	Vertical Text
Label	Label

Figure F.5-1—Examples of Horizontal Text (Preferred) and Vertical Text

F.5.3 Menus

a. Popup and drop-down menus should appear near components related to the menu selections.
b. Popup and drop-down menus should default to a location that does not obscure associated data on the referencing display.
c. Popup menus must not cover critical information or information needed to perform the task.
d. Information should be no more than 4 levels deep (i.e., no more than 4 actions to access) to acquire from a display.
e. Menu items should be listed in an order based on sequence of operations, urgency, functionality, or frequency of use. If no basis for menu item order exists, items should be listed in alphabetical order.

F.5.4 Buttons

a. Buttons must be labeled, either on the button surface or just outside the button edge.
b. Buttons must have labels that are visible in all states.
c. Buttons when actuated must change appearance.
d. A grouping of related buttons should be visually separated from other groupings or from graphical or virtual borders.

F.5.5 Alphanumeric Inputs

a. When a specific data entry format is required, format cues must be provided (e.g., mm/dd/yyyy).
b. The system must provide an indication when crew enters invalid entries.
c. Text within data entry fields must be left aligned with sufficient width to show the longest possible word.
d. Numbers within data entry fields should be right aligned with sufficient width to show the longest possible value, including the size of any data quality indicators.

F.5.6 Numbers

a. Values for the same type of parameters must be shown in the same units.
b. Units of measure must be displayed for each numeric value or for each group of numeric values where the units are the same.
c. The number of decimal places shown must be the number required by operators to perform the associated task.
d. Where numeric data is presented as a vertical group, the decimals should be vertically aligned.

e. Where numeric data is presented as a vertical group, whole numbers should be vertically aligned with the implied decimal place.
f. Numbers that have absolute values less than 1 must be displayed with a leading zero prior to the decimal point (e.g., 0.25 rather than .25).
g. Numbers that have absolute values greater than or equal to 1 must be displayed with leading zeroes suppressed (e.g., 3.14 rather than 03.14).
h. The plus "+" sign for numerical data must be suppressed, except when required for the performance of the associated task.
i. The minus "-" sign must always be displayed for negative numbers.
j. When a numeric value contains five or more digits, a comma should be displayed before every third digit, counting to the left from the decimal point. (e.g., XX,XXX.YY).

F.5.7 Icons and Symbols

a. Standard, universally recognized iconography and symbology should be used wherever possible (e.g., trash can for "delete", media control symbols for "play" and "pause").
b. Icons must be visually distinct from one another.
c. Symbols must be visually distinct from one another.
d. Icons and symbols must be selected from the standard Icon and Symbol library.

F.5.8 Graphs

a. Each graph must have a unique title located above the graph.
b. Graphed data that is historical must be distinguishable from live data via labeling.
c. A label and units must be provided for each axis of a graph.
d. Each parameter must be labeled or accompanied by a legend.
e. Value labels at major tick marks on the x- and y-axis must be provided.
f. When it is important to identify out-of-range or off-nominal values, they must be highlighted (e.g., via color and a numeric/text indicator or limit line).
g. Graphs should allow for re-scaling or zooming upon user request.

F.5.9 Schematics

a. Each schematic must have a unique title.
b. Each object on the schematic must be labeled or have an identifier available on request.
c. Lines representing flows that cross and are not physically connected must be shown as crossing lines (see Figure F.5-2—Lines Not Physically Connected).

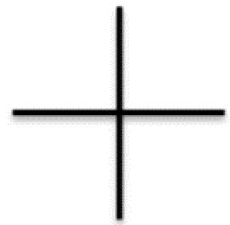


Figure F.5-2—Lines Not Physically Connected

d. Lines representing flows that cross and are physically connected must be shown as crossing lines with a dot at the conjunction (see Figure F.2-3—Lines Physically Connected).

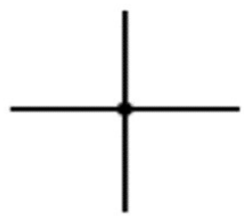


Figure F.5-3—Lines Physically Connected

e. When a schematic depicts a single type of line (for example, data, video, or power transmission path), the line should be solid. However, if there is more than one line type, mixed line types (e.g., dashed, dotted, colored, etc.) must be used.
f. Each line type must be identified with a label or a legend.
g. Line types should be consistent within a subsystem.
h. Lines used to represent organization and system boundaries must be visually distinct from lines used to represent flow.
i. Where flow is important and cannot be inferred by display layout, arrows must be used to indicate the direction of flow.

F.5.10 Color

a. Color must be used to convey meaning, and not for decoration or aesthetic purposes.
b. The meanings in Table F.5-1—Required Color Usage and Its Meaning, must be represented with the colors shown.

Table F.5-1—Required Color Usage and Its Meaning

Meaning	Color
Highest alert level, emergency, warning, failed	Red
Second highest level, caution, off-nominal, trip, manual override, or attention required	Yellow
Advisory	Blue
Unavailable, unselectable	Gray
Missing or stale data	Cyan

c. The meanings in Table F.5-2—Recommended Color Usage and Its Meaning, should be represented with the colors shown.

Table F.5-2—Recommended Color Usage and Its Meaning

Meaning	Color
Electronic Procedures and system directed	Magenta
Commandable element background	Dark Green
Navigation and Cursor Outlines	Bright Green

d. Colors selected outside of Table F.5-1 and Table F.5-2 must be applied in accordance with a provider-defined standard color table to ensure consistency.
e. For critical information and critical tasks when color is used to convey meaning, the system must provide an additional cue.
f. Contrast between characters and background must be 6:1 or greater (10:1 preferred). Note: contrast ratio may be calculated using an online contrast analyzer (e.g., webaim.org). Verification standards can also be found in the ISO (International Organization for Standardization) documents [ISO/IEC JTC 1/SC 29] for coding of picture/multimedia information, IEC (International Electrotechnical Commission) [TC100 + TC110] for video, display quality assessment and measurement methods. Specific contrast issues related to the use of transparent displays have not been addressed in this revision but will be addressed in future revisions.
g. Reverse video (e.g., inverted background/foreground color) must be reserved for events that require immediate crew attention or action.

F.5.11 Flashing

a. Flash coding must be reserved for events that require immediate crew attention or action.
b. Low flash rate must be reserved for lower priority notifications or text at a frequency of 0.8 Hz with duty cycle of 70% on.
c. High flash rate must be reserved for higher priority notifications (non-text) at a frequency of 3 Hz with duty cycle of 50% on.
d. Flashing must be synchronized across all cockpit display units.

e. The display must allow crew-controlled termination of flashing that persists more than 10 seconds.
f. If text that must be read flashes, the text must alternate intensities with a lower intensity that remains legible.

F.6 SPECIAL PURPOSE ELEMENTS

F.6.1 Time

a. Time in the standard format must always be displayed. Standard format is listed in bullet f.
b. Timers based on an absolute reference time (a Global Positioning System (GPS) time for example) must show negative time, counting to zero, before the reference time is reached, then positive time, counting up from zero, after the reference time has passed.
c. Timers with a set countdown (or count up) interval, must start immediately when the user commands it. For example, a timer can be set for a 30minute countdown and started based on the occurrence of a certain event.
d. Additional time systems, (e.g., Phased Elapsed Time (PET), Mission Elapsed Time (MET)) must be available for display.
e. All displayed times must be labeled with the time system used.
f. Time must be displayed using a 24-hour clock in the following format (Note: leading zeros are suppressed in day field): label dddd/hh:mm:ss (e.g., MET 57/14:08:33, or MET 1089/13:03:01).

F.6.2 Automation

a. The system must provide an indication of the current level of automation (e.g., full/partial/none, auto/manual, enabled/ inhibited).
b. The system should indicate whether the human operator or the system is supposed to perform a particular task at a specific time.
c. The status of an automated process must be shown (e.g., running, paused, faulted, completed, overridden, stopped).
d. Historical performance information on automated processes must be available for display.
e. Information from the automated system must avoid anthropomorphic phrasing.
f. The system must provide the human operator the ability to check information and configurations used for automated systems.
g. Automated systems that provide decisions or recommendations must provide explanation with rationale for the decision or recommendation.
h. When a human operator attempts to override or shut down an automated system, a message describing consequences (e.g., impacts to safety, hardware or software damage, timely completion of the task) must be displayed prior to executing the selected command.
i. The system must alert the human operator when a problem or situation is beyond its capability to assist with resolution or provide consequence guidance.

j. Source of control should be clearly indicated (Autonomous system vs Crew software commanding vs Crew manual commanding vs Remote operator commanding) for all systems (i.e., flight path, attitude, etc.).

F.6.3 Electronic Crew Procedures

a. The system must indicate to the crew which step in an electronic crew procedure is currently being executed.
b. The system must indicate to the crew which steps in the electronic crew procedure have been completed.
c. The system must allow the user to manually indicate the step being executed.
d. The system must allow the user to manually indicate that a step has been completed.
e. The system must notify the crew whenever crew attention is required to initiate or return to an electronic crew procedure.
f. The system must provide a method for viewing prior and future steps in the electronic crew procedure.
g. The system must provide a method for the crew to provide comments or notes about electronic crew procedures.
h. The system should provide a method for the crew to make real-time insertion, deletion, and rearrangement of electronic procedures.

F.6.4 Alerts

a. Emergency (E) and Warning (W) alerts must be associated with red symbology/text.
b. Caution (C) alerts must be associated with yellow symbology/text.
c. Advisory (A) alerts must be associated with blue symbology/text.
d. The Alerts display must display or make available on request the following parameters: Active Emergency Count, Active Warning Count, Active Caution Count, Unacknowledged/New Event Count, and a queue of unacknowledged events.
e. The Alerts display must allow crewmembers to search for events by ID or name. This search includes both active and inactive events.
f. The Alerts display must display the following for each event: Event Priority (E, W, C, A), Name, Event ID, Timestamp, System, Module/Element, Active State (active events are displayed by default), Annunciation State (Inhibit, Suppress), Acknowledge State, and event details including root cause (if available).
g. The Alerts display must allow active messages to be sortable by: Event Priority (E, W, C, A), Timestamp, System, Module/element, and root cause, if available.
h. Emergency, warning, and caution events must provide a link to access associated malfunction procedures.
i. The Alerts display must allow crewmembers to perform the following actions for each event: Acknowledge, Suppress, Inhibit, Enable.
j. The Alerts display must allow crewmembers to suppress indicators for individual events.
k. The Alerts display must allow crewmembers to silence audible annunciations for all events with a single action.