NASA-STD-3001 Technical Brief

Mortality Related to Human Spaceflight

OCHMO-TB-012
Rev A

Executive Summary

Despite screening, health care measures, and safety precautions, crewmember fatalities are possible during spaceflight. Programs must establish comprehensive plans that make the appropriate decisions in terms of protecting the crew and mission objectives, determining the cause of death, and handling of the remains with dignity, honor, and respect while working with the crew's families, other federal agencies, and international partners, while respecting the spiritual, religious and cultural aspects of remains handling. A spaceflight-related fatality event may occur during any operational mission phase (pre-flight, inflight, or post-flight).

Relevant Technical Requirements

NASA-STD-3001 Volume 1, Rev C

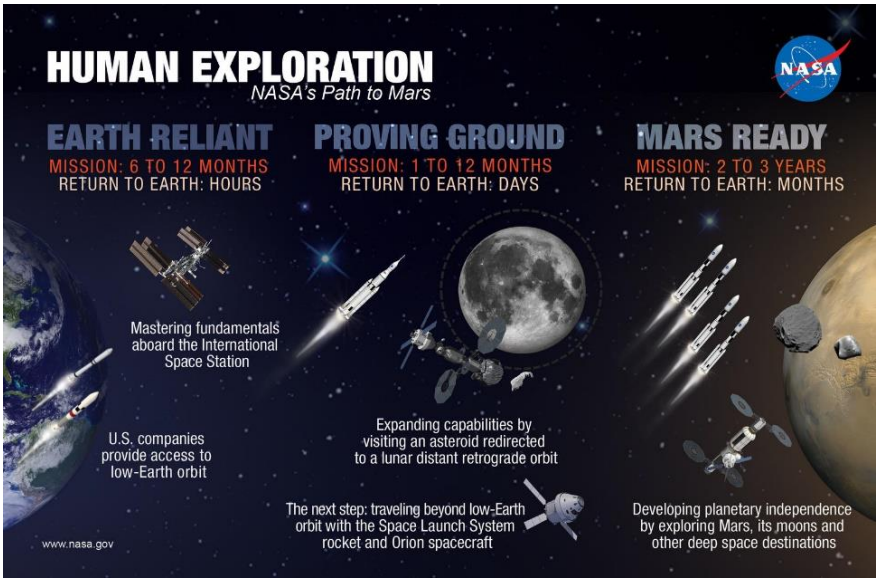
[V1 3004] In-Mission Medical Care
[V1 3010] Termination of Care
[V1 3050] Pre-Mission Crew Mortality Plan
[V1 3051] Pronouncement of Crew Death
[V1 3052] In-Mission Forensic Sample Collection
[V1 3053] Crew Mortality Remains Return to Earth
[V1 3054] In Situ Disposition of Deceased Crewmember Remains
[V1 3055] Surviving Crew Support
[V1 3056] Crew mortality Mishap Investigation Plan
[V1 5001] Medical Training
[V1 5002] Astronaut Training
[V1 5003] Crew Medical Officer Medical Training
[V1 6002] Private Medical Communication (PMC) Schedule
[V1 6003] Private Medical Communications Information Delivery
[V1 6004] Behavioral Health and Performance Provisions

NASA-STD-3001 Volume 2, Rev D

[V2 3006] Human-Centered Task Analysis
[V2 6022] Atmospheric Monitoring and Alerting Parameters
[V2 6023] Trace Constituent Monitoring and Alerting
[V2 6061] Environment Cross-Contamination

Overview

- As we return human missions to the moon and begin the exploration of deep space and other planetary bodies such as Mars, the risks associated with spaceflight increase, particularly as a function of distance from Earth. Crew fatalities during spaceflight could be caused by a myriad of events, which can include medical events, vehicle emergency events such as fire, depressurization, and release of toxic materials into the cabin, electrical shock, and insufficient access to food and water due to supply, contamination, or spoilage.



- Future missions and program development are now working towards understanding the needs of vehicle design and crew safety for any scenario, including those that are now exceeding low earth orbit.
- The death of a crewmember requires medical, psychological, ethical, religious, cultural, and legal considerations and would pose significant challenges regarding pronouncement of death, forensic sampling, and preparation, containment, and, potentially, final disposition of the remains.
- If a death were to occur during a mission, one of the most immediate and main concerns would be how to ensure the safety of the remaining crewmembers. The health of the surviving crew must be maintained within the habitable environment as after death, the body begins to decompose and becomes a biohazard. In the closed atmosphere of a space vehicle, the natural byproducts of decomposition and/or potential pathogens released during the decomposition process could contaminate the enclosed vehicle environment.
- Another complex consideration are the responsibilities of the living crewmembers to the deceased. The goal is to ensure that the procedures are performed as set forth, professionally, and with dignity and respect without compromising the health of the surviving crew.
- To support this goal, the crew needs to receive adequate training in the handling of the remains. Considerations for the implications of long-term interment or storage of remains also require significant forward planning along with any associated provisions, as well as assessment of surviving crewmembers' physical safety and health, and of psychological health before being attempted.
- In the aftermath of a fatality event, there are also time-based limitations on when certain handling procedures can be performed due to natural processes occurring with the remains. Additionally, ambient environmental conditions in spaceflight missions are different than on Earth with respect to temperature, humidity, oxygen, and pressure levels, all playing a role in decomposition of the remains.

Reference Data

United States Military Procedures

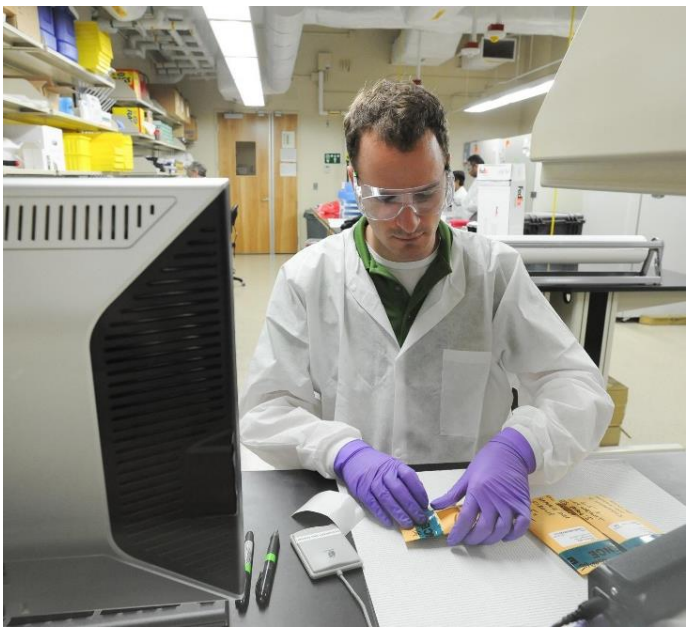
International fatalities are sent to Dover Air Force Base in the U.S. for processing. The remains are first checked for any unexploded ordinance or other remaining threats. Diagnostics/forensics analysis is performed, and then the remains are taken to Mortuary Affairs and dressed in their uniforms.

The family is contacted to determine where they wish the remains to be transported. Compared to spaceflight, the military has relatively quick access to refrigeration. The remains are stored at a temperature that suppresses decomposition.

The Federal Bureau of Investigation (FBI) and the Armed Forces Medical Examiner are responsible for the complete remains processing.

The staff at the Air Force Mortuary Affairs Operation (AFMAO) establishes identification through DNA, dental, and fingerprint analysis, and autopsy of the remains is performed to determine the cause of death. They also prepare fallen members for transport to their final destination as determined by the family.

Dover Air Force Base



DNA Identification Laboratory
at Dover Air Force Base

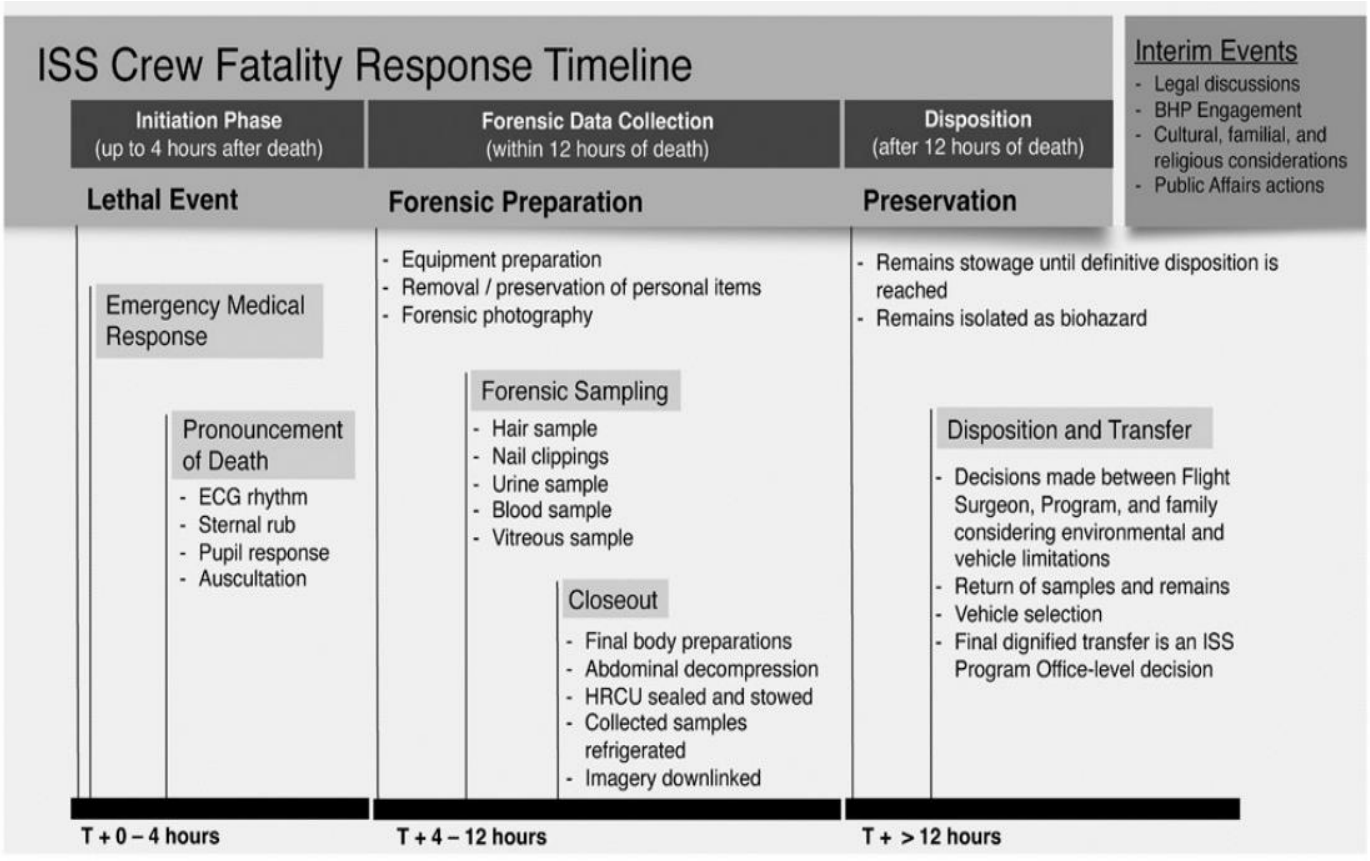
Reference Data

NASA (ISS) Procedures

In the case of a single crewmember fatality in orbit on the ISS where the circumstances do not drive an emergent evacuation of ISS by surviving crewmembers, procedural goals include the collection of forensic data, management of remains to ensure containment and prevent contamination of the survivors' habitable environment, and, by providing effective isolation, ensure time for the determination of best options for disposition of remains.

ISS has small-volume refrigeration and freezer capabilities with temperature storage ranges of –160°C to +4°C. The volume available is exceptionally limited, and using this space would require sacrificing other payloads or items requiring refrigeration. Large-volume refrigeration capable of preserving a human body is unavailable onboard current launch vehicles or on the ISS. In 2012, an unaltered commercial off-the-shelf human remains containment unit (HRCU) was flown to the ISS along with a forensic sampling kit and charcoal odor control filtration canisters.

The final disposition of remains will follow, with the ISS Program Office responsible for the final determination of remains disposition. For a crew fatality occurring on the ISS, options would be limited to the return of remains, jettison to a disposal trajectory, or destructive reentry.



Operational considerations for crew fatality on the International Space Station, from Stepaniak et al. (2023)

Application

Legal Jurisdiction

Article VIII of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies specifies that whenever one of the nations that's a party to the treaty launches an object — i.e., a spacecraft, satellite or space station — into space, or builds one on a celestial body, that nation retains jurisdiction and control over it. Due to this treaty, and subsequently the various countries involved in a program, there will likely be complexities in determining who has legal jurisdiction over an investigation and even the crewmember remains. It is imperative that agreements are in place prior to a mission to ensure the proper handling of an investigation and maintaining international relations.

Investigations are necessary to determine the cause and manner of death and to provide information to prevent future fatalities. For NASA astronauts, the medico-legal jurisdiction is delegated from the NASA Administrator to the Armed Forces Medical Examiner System (AFMES) per current policy NASA-SP-2020-5006891, Spaceflight Mishap Investigation Flight Surgeon Handbook.

The plan will need to consider legal jurisdiction, which will involve working with several organizations, including:

- **Federal Bureau of Investigation (FBI):** In the event of a crewmember fatality, the role of the FBI is to investigate the incident in collaboration with the flight surgeon.
- **National Transportation and Safety Board (NTSB)**
- **Federal Aviation Administration (FAA)**
- **Department of Defense (DoD)/U.S. Air Force (USAF)**
- **Commercial Providers:** Each commercial entity may choose to conduct its own investigation in parallel with those conducted by the NTSB.
- **Presidential Commission:** According to the NASA Authorization Act of 2005 (Public Law 109-115, Section 821), any vehicular disaster involving significant injury or loss of life to onboard NASA crewmembers mandates the establishment of a Presidential Commission, with federal oversight of mishap response and investigation.

The death of a crewmember in space may require collaboration and cooperation with international agencies:

- NASA has memoranda of understanding with each of its international partners in support of the International Space Station and all other international programs. The death of a crewmember might require coordination between international agencies in accordance with international treaties.
- International partners must be consulted and agree on the Crew Mortality Plan decided for the mission.
- In some countries, family consent must be given prior to forensic sample collection.
- Conditions in space may not be compatible with all cultural and religious traditions.
- Furthermore, nations have legal jurisdiction that extends into space and stretches outside the confines of Earth:
  - If the death of a U.S. crewmember is caused by another U.S. crewmember, the FBI and the federal prosecutors would be within their authority to investigate.
  - For example, if on the International Space Station, a death of a crewmember is caused by another crewmember of a different country, Article 22 of the 1998 Intergovernmental Agreement concluded between the parties, concedes jurisdiction to the state of nationality of the offender.

Application

Crew Mortality Plan

The plan needs to consider the following factors: minimizing risk to surviving crewmembers, communications, potential forensics collection, biohazard containment, and legal jurisdiction, which may involve working with other government agencies and international partners.

The program will develop and execute plans for handling deceased crewmembers that are culturally, socially, biologically, and physically acceptable. If a crewmember death occurs during a mission, the following aspects must be addressed:

- First and foremost, the safety of surviving crew to prevent additional crew loss
- Pronouncement of death and recording of certificate
- Forensic (medico-legal) considerations
- Preparation, containment, stowage, and disposition of remains

Pronouncement of Death

- It must be defined in advance who can pronounce the crewmember's clinical death, as well as how and where the medical record will be filed.
- It must be defined in advance who has the responsibility for the death certificate, as well as how and where it will be filed.
- It must be understood that cause of death may be approximate as a direct physical medical assessment or autopsy may not be possible.

Environmental Monitoring

Toxicological and analytical hardware will be needed to monitor the environment for CO_2, hydrogen sulfide, methanethiol, and other gases that may permeate into the vehicle atmosphere as a result of decomposition, which are further detailed in ***[V2 6022] Atmospheric Monitoring and Alerting Parameters*** and ***[V2 6023] Trace Constituent Monitoring and Alerting.***

[V2 6022] Atmospheric Monitoring and Alerting Parameters 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.

[V2 6023] Trace Constituent Monitoring and Alerting 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.

From: NASA-STD-3001 Volume 2 Revision D

Application

Forensics (Medico-legal Considerations)

In-mission forensic sampling may or may not need to be performed (depending on mission type, duration, crew capability, and if immediate return of the body is possible). Upon return of the crewmember's remains or forensic samples:

- For NASA Astronauts, forensic analysis on any samples will be performed by the AFMES.
- For international partner astronauts, forensic sample collection and subsequent analysis will first be coordinated, which would have been done prior to the mission, with their country's respective medico-legal authority and prior family consent.

The manner of death will not only impact the handling of the remains, but also the need for forensic collection.

Forensics may be needed in the event of an investigation or to document circumstances surrounding the manner or cause of death of a crewmember. These samples will be both biological and non-biological, as well as require various levels of storage requirements, contamination protection, and sampling type.

- May also include photo documentation of the remains and circumstances surrounding the manner of death, as well as the removal of the suit, clothing and other equipment, and personal effects.
- Biological samples may include fingernail clippings, hair samples, urine, blood, vitreous fluid.
- Some samples will require collection and refrigeration within 12 hours of death with continued cold storage until evaluation.
  - Hair and fingernail clippings allow for longer sampling window and do not require refrigeration.
- Due to the constrained environment, comprehensive sampling may not be available, therefore the data may not be available to determine cause or manner of death.

Forensic sample collection. Source: Discover Magazine

Application

Behavioral Health Support

- Program development of an integrated behavioral contingency response protocol identifies and manages adverse behavioral health impacts in affected members.
- Private communication and video conferences for surviving crewmembers and having appropriate bandwidth required to facilitate increased need for support, with potential simultaneous use with family and friends.
- Ceremonial and cultural/religious considerations for honoring crewmembers and dignified transfer of remains (e.g., private area needed for crewmembers to hold a ceremony, having storage for personal effects to return to family members).
- Family support: Assigned Crew Surgeons should be contacted to manage any family medical or psychological support requests. This is done in tandem with the Family Support Office and Casualty Assistance Calls Officer (CACO).
- Surviving crew will experience significant psychological impacts from the death of their crewmate, which would be accentuated by having the remains onboard for an undetermined period of time, as well as potentially having to perform forensic sampling.
- Ground personnel support: managing adverse behavioral health impact via critical incident stress management teams.
- Prevention of satellite imagery of the remains, which can be protected with a shroud or covering.

NASA Astronauts

- In accordance with current NASA policy, the AFMES is responsible for the determination of the cause of death and manner of death.
- If the remains are able to be transported back to Earth, the AFMES will conduct an autopsy examination.
- If forensic samples were taken, these will be provided to AFMES to assist in cause of death and other determinations.
- Following this examination, any remains will be returned in a dignified manner to the families.

Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders

Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team

Application

Disposition of Remains

- Plans need to provide a storage solution for a deceased crewmember.
  - Crewmember remains should be placed inside a containment option that must prevent odor leakage and environmental contamination.
  - Adequate restraining devices are also needed for each vehicle to secure the body during transit (e.g., boot clips, cargo straps, suit umbilical cap).
- Sec. 317 (a) Recovery and Disposition Authority of the National Aeronautics and Space Act of 1958, specifies:
  - Treatment – *Each crewmember shall provide the Administrator with his or her preferences regarding the treatment accorded to his or her remains and the Administrator shall, to the extent possible, respect those stated preferences.*
- For short-duration missions, e.g., low-Earth orbit, the body may be returned to Earth or Earth-orbit burial
- For deep space exploration missions, turning back may not be an option due to the duration of the trip (i.e., “burial at sea”, or burial on planetary surface may need to be considered).
  - Can include deep space trajectory, solar injection, or planetary orbit
  - Jettison of crew remains will need to account for orbital mechanics and appropriate tracking to ensure they will not end up in an unknown location or surface.
  - Considerations for vehicle design for jettison (i.e., does the vehicle have an airlock or resources to do multiple depressurization/repressurization cycles, will the containment used to be adequate for deep space conditions).
- Programs need to make the appropriate risk trades in terms of protecting the crew, mission objectives, physical and emotional health, and the handling of the remains.
- International partners need to be consulted to agree on the body disposition plan.

Transportation of remains should take into account the crew remains' stage of decomposition as they are moved through the various phases of surface or flight activities, which may include:

- Planetary surface-suited operations back to the habitable location or ascent vehicle
- Relocation of remains to the site of interment
- Ascent vehicle to orbiting vehicle
- Return to Earth in the transport vehicle
- Vehicle for return into Earth’s atmosphere

[V1 3054] In Situ Disposition of Deceased Crewmember Remains The program shall meet planetary protection regulations in the case of in situ or jettison disposition of the remains of a deceased crewmember.
From: NASA-STD-3001 Volume 1 Revision C

Application

Planetary Protection

Planetary Protection is vital in protecting the scientific integrity of our missions and keeping Earth safe.

- Planetary Protection is the practice of protecting solar system bodies from harmful contamination by terrestrial materials to enable scientific exploration and protecting the Earth-Moon system from possible harmful extraterrestrial contamination that may be returned from other solar system bodies.
- Prevention of forward contamination requires understanding biological containment. This includes limiting the transfer of our terrestrial life onto other potentially habitable solar system bodies.
- Preventing uncontained extraterrestrial materials being brought back to the Earth-Moon system (backward contamination).

This plan begins prior to the start of any mission by understanding the mission science and operational objectives, which is also based on the biological sensitivity of the destination. Logistically, containment of remains will require significant mass and volume to permanently contain or prevent contamination of another planetary body from either burial on a surface or jettison into space, which could be mission prohibitive.

[V2 6061] Environment Cross-Contamination The system shall provide controls to prevent or otherwise 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.
From: NASA-STD-3001 Volume 2 Revision D

NASA-STD-8719.27 Implementing Planetary Protection Requirements for Space Flight

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Application

Considerations for Disposition of Remains and Planetary Protection

Interment on the surface, or within a surface-based structure or non-returning vehicle

- Surface interment contingency plans should be dependent on planetary classifications to prevent local exposure to non-native biologics in designated special regions. The alternative would be to return remains to orbit, which is preferred from a Planetary Protection standpoint. For planetary bodies such as Mars, this may or may not be feasible.
  - A catastrophic event with no survivors for example would preclude any concerted containment activities within a meaningful time period to prevent biological contamination.
- Short-term storage prior to transport
  - Assumes a surviving crewmember can safety handle remains.
  - Contingent on surviving crewmember(s) capability (following possible deconditioning due to duration of low/no gravity) to relocate remains, as well as preparation of deceased crew, if suited.
  - Hardware available to assist in storage or transport.
- Long-term interment
  - Assumes surviving crewmember can safety handle remains.
  - Viable containment method with durability of preferably 50+ years, or seek containment with available resources such as within spacesuit, surface habitat, vehicle, etc.
  - Shrouding of remains where possible prevents satellite imagery capturing views that may be upsetting to surviving family and crew.
- Documentation of the site of the fatality and interment, included in End-of-Mission Planetary Protection Report
  - Level of detail will need to provide the care and respect for the crewmember and family.
  - Notification of the international scientific community to ensure future science objectives are not compromised by those visiting that area.
- Estimation of microbial populations, as well as potential zone of microbial population spread over time, which may be impacted by environmental conditions and method of interment.
- Spiritual, cultural and religious aspects of the disposition of remains on the lunar surface must also be considered when developing these plans.

Jettison of remains from vehicle while in orbit

- Consider the potential re-entry of remains and organic materials into any planetary atmosphere.
  - Leaving planetary orbit prior to jettison is advisable.

Application

Additional Considerations

Within hours of death, remains will naturally alter and begin the stages of decomposition, which is dependent on environmental conditions. These processes will become visually obvious and impact crew health and safety from the released decomposition products.

Psychological impacts must be minimized to the remaining crew who will be required to disposition remains, perform any forensic or investigation procedures, physically move or retrain remains, or collocate in the same vehicle with remains. Considerations for various countries of vehicle or crew origin, cultural preferences, and governmental procedures will impact protocols following the death of any crewmember during a mission.

Environmental conditions exposure at the time of death and thereafter

- Altered microbiome on and within the crewmember, as well as any microbial presence found within the habitable environment
  - Planetary atmospheric conditions on bacterial growth and subsequent on process following internment
  - Long-term and permanent interment impacts to planetary environment, including biome and water, as well as the environmental conditions affecting containment unit
- Heat transmission in 0g and thermocycling that will impact the natural processes and the timeline to disposition or handle the remains for later transport
- Cold Temperature
  - Acceleration of rigor mortis-like behavior of the remains
  - Will halt or slow down the decomposition
- Hot Temperatures
  - Accelerates the decomposition of the remains
  - Compromises the integrity of any forensic samples needed or collected
- Moisture
  - Accelerates the decomposition of the remains
- Oxygen availability (or lack thereof) is an important factor that will affect rate (and type) of decomposition
- Naturally occurring gasses and fluids within the body will behave differently in a 0g environment
- Stowage and transport containment for Earth-return will need to consider natural process, including off-gassing, to protect remaining crew, including the dynamic loads experienced during landing operations

Accident Cases

- Need plans for accidents with and without survivors, including rescue and subsequent hazards to survivors
- Difficulty of assessing crewmember while suited
- Possible environmental contamination (chemical and/or biological) to water, ice, or other resources

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information to reflect the revisions to language throughout both volumes of NASA-STD-3001
- Updated/added website links due to new NASA website launch
- Reorganized content flow
- New references and information added regarding ISS procedures and taphonomy details

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 1 Revision C

[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence- based PRA, clinical practice guidelines and expertise, historical review, mission parameters, and vehicle- derived limitations. These analyses should consider the needs and limitations of each specific DRM and vehicles. The term "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 on Earth. In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, are to include, but are not limited to: (see NASA-STD-3001, Volume 1 Rev C for full technical requirement).

[V1 3010] Termination of Care Each human spaceflight program shall have criteria for termination of care available prior to flight.

[V1 3050] Pre-Mission Crew Mortality Plan The program shall develop and execute a Crew Mortality Plan and determine legal jurisdiction prior to each mission (including pre-flight activities, launch, operations, and landing).

[V1 3051] Pronouncement of Crew Death The program shall define the process to medically assess the death of an in-mission crewmember and legally record the pronouncement of death.

[V1 3052] In-Mission Forensic Sample Collection The program shall have the capability to obtain in-mission forensic evidence from a deceased crewmember and return this evidence to Earth.

[V1 3053] Crew Mortality Remains Return to Earth The program shall be capable of returning the remains of a deceased crewmember back to Earth.

[V1 3054] In Situ Disposition of Deceased Crewmember Remains The program shall meet planetary protection regulations in the case of in situ or jettison disposition of the remains of a deceased crewmember.

[V1 3055] Surviving Crew Support The program shall provide behavioral health support to the deceased crewmember's family, surviving crewmembers, and support team in-mission and post-mission.

[V1 3056] Crew Mortality Mishap Investigation Plan The program shall have plans in place prior to a mission to gather the appropriate data to support a Presidential Commission mishap investigation.

[V1 5001] Medical Training Medical training shall be provided to crewmembers, flight surgeons (FSs), mission control support staff, and other ground support personnel (GSP).

[V1 5002] Astronaut Training Beginning with the crewmember candidate year, general medical training, including but not limited to, first aid, cardiopulmonary resuscitation (CPR), altitude physiological training, carbon dioxide exposure training, familiarization with medical issues, procedures of spaceflight, psychological training, toxicology, medical equipment, and supervised physical conditioning training shall be provided to the astronaut corps.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 1 Revision C

[V1 5003] Crew Medical Officer Medical Training Crewmembers who have received a mission assignment as a Crew Medical Officer (CMO) shall be provided with detailed and specific medical training, including but not limited to, health issues, space physiology, behavioral health, medical procedures, medical equipment, toxicology, and countermeasures.

[V1 6002] Private Medical Communication (PMC) Private medical communications shall be scheduled on a routine basis, as determined by the Flight Surgeon, at a frequency dictated for short- or long-duration missions.

[V1 6003] Private Medical Communications Information Delivery Private Medical Communications information that is sent to/from the ground via spacecraft communication systems shall be considered private communication.

[V1 6004] Behavioral Health and Performance Provisions Programs shall implement psychological/behavioral health support programs for the crewmembers, key ground personnel, and crewmember families throughout the mission.

NASA-STD-3001 Volume 2 Revision D

[V2 3006] Human-Centered Task Analysis Each human space flight program or project shall perform a human-centered task analysis to support systems and operations design.

[V2 6022] Atmospheric Monitoring and Alerting Parameters 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.

[V2 6023] Trace Constituent Monitoring and Alerting 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.

[V2 6061] Environment Cross-Contamination The system shall provide controls to prevent or otherwise 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.

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