Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials

Human Health and Performance Directorate

Biomedical Research and Environmental Sciences Division

Space Toxicology Office

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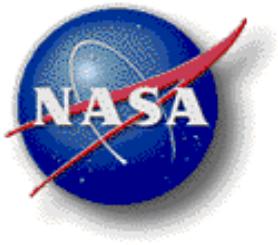

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NASA APPROVAL SHEET

Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials

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CHANGE HISTORY

REVISION/ CHANGE	DATE	AUTHORIZATION	DESCRIPTION OF CHANGE
Baseline	09/1997		Initial Release.
Revision A	04/30/2014	HHPD-BRES_CB-14-002	Revised / updated to reflect changes to NASA programs. Update to process descriptions throughout document. Revision of Table 1.

Section Page

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THIS DOCUMENT

This document describes the criteria and procedural guidelines used by the NASA / JSC Toxicology Office (JSC STO), to perform toxicological evaluations. The JSC STO is responsible for conducting toxicological assessments and assigning toxic hazard levels (THLs) for essentially all chemicals and test materials to be used in or transported to the habitable areas of U.S. spacecraft, non-U.S. spacecraft inhabitaed by U.S. crewmembers or habitable areas of off-Earth habitats where U.S. crewmembers would be present, including chemicals carried by visiting spacecraft (visiting vehicles) to and from the International Space Station (ISS). Biohazard assessments for biological materials used in payload experiments are performed by the NASA Biosafety Review Board. Radioactive materials are assessed by the Space Radiation Analysis Group for radiation hazards; the flammability rating on flammable materials is assessed by the JSC Materials and Processes Branch, ES4. This document will focus on the assessment of chemically-induced toxicity hazards. The toxicological assessments, together with assessments on radioactive, biological, physical, and flammability hazards, are incorporated into a mission-specific Hazardous Materials Summary Table (HMST).

1.2 PURPOSE OF TOXIC HAZARD ASSESSMENTS AND THE HAZARDOUS MATERIALS SUMMARY TABLE

Safety is of the highest priority to NASA. Thus, minimizing adverse effects on crew health from exposure to hazardous materials in spacecraft is a major NASA objective. In supporting NASA's safety objective, the JSC STO assumes responsibility for compiling information on, assessing the potential adverse effects of, and assigning THLs to all in-flight chemicals/materials to which the crew might be exposed. These include all test sample materials reviewed by any governing NASA Safety Panels (e.g. the NASA Payload Safety Review Panel (PSRP) and the Safety Review Panel (SRP)) for use or transport in the pressurized volume of the ISS or other space habitat as well as other potentially toxic materials not reviewed by the governing safety panel(s). These materials may include utility chemicals and chemicals in government furnished equipment (GFE) and risk mitigation experiments (RMEs), etc. The assigned hazard levels are used by payload, system, or GFE developers as criteria in the design of flight hardware to assure adequate containment. For experiments, systems, and other payloads, including GFE, flying in the pressurized volume of NASA spacecraft (or other vehicles docking to the ISS), it is the responsibility of the governing NASA safety panel to certify that the design of equipment provides adequate containment for the assigned THL of the materials it contains. The assigned

THLs and corresponding medical protocols are compiled in a .pdf-formated Hazardous Materials Summary Table (HMST) and in an electronic HazMat records database. These files are created and maintained by JSC STO toxicologists. Mission-specific HMST record sets are utilized by JSC Safety Panels when reviewing payload and systems chemicals and materials. In addition, the HazMat HMST records are used by on-board ISS crewmembers and ground-support professionals in the event of on-orbit chemical/materials leaks during missions

1.3 COMPILATION AND DISTRIBUTION OF TOXICOLOGICAL HAZARD INFORMATION

The assessment process begins with payload investigators, system/GFE managers, or coordinators submitting information and relevant data to the JSC STO on payload chemicals as described in *Requirements for Submission of Data Needed for Toxicological Assessment of Chemicals to be Flown on Manned Spacecraft* (JSC 27472) or its subsequent revisions. The relevant data, together with the toxicological assessments and assigned THLs, are entered into a computerized database from which an HMST is generated. The appropriate sections of the HMST for a particular mission are provided to the payload, system, or GFE organizations, as appropriate, to verify the accuracy of the information on the chemicals or biological materials that they intend to fly. Printed or electronic copies of the relevant pages of the HMST are provided to payload, system, or GFE hardware customers and an appropriate review board to support safety assessments for payload hardware. After verification, the final HMST is provided to flight surgeons, biomedical flight controllers (BMEs) and other mission support personnel. Copies of the HMST are used by payload, system, or GFE hardware customers to verify sample loading prior to hardware turnover for pre-launch stowage in spacecraft. Before a spacecraft launch, the data from the HMST for that mission are transferred to mission-specific electronic files, which are provided to mission support personnel for loading onto the onboard computers and the flight surgeon/BME's computer in the Mission Control Center to provide real-time toxicological support.

2.0 DEFINITION OF TOXIC HAZARD LEVELS (THLS)

The definitions and criteria for THLs are shown in Table 1. The THL of an escaped chemical depends on its physicochemical properties (e.g., gas, liquid, solid, particle size, acidity, alkalinity, and corrosiveness), its quantity, its biological effects (e.g., irritancy, carcinogenicity, systemic toxicity), and the ease with which the chemical is removed from the environment. The removal rate depends on a combination of the characteristics of the spacecraft's life support system and the chemical's physicochemical properties.

Table 1 General Description of Toxicological Hazard Levels

Toxicity Hazard Level (Hazard Classification) (Color Code) Physical State	Irritancy	Systemic Effects	Containability and Mitigation
0 (Negligible) (Green) Gas, solid, or liquid	Slight irritation that lasts <30 minutes and will not require therapy.	None	May or may not be containable. No PPE required but may be donned by crew at their discretion.
1 (Critical) (Blue) Gas, solid, or liquid	Slight to moderate irritation that lasts >30 min and will require therapy	Minimal effects, no potential for lasting internal tissue damage.	May or may not be containable. Crew should don PPE according to applicable procedures/flight rules.
2 (Catastrophic) (Yellow) Either a solid or nonvolatile liquid	Moderate to severe irritation that has the potential for long-term performance decrement and will require therapy. Eye Hazards: May cause permanent damage.	Minimal effects, no potential for lasting internal tissue damage.	Can be disposed of and contained by a cleanup procedure. Crew should don PPE according to applicable procedures/flight rules.
3 (Catastrophic) (Orange) Either a solid or low-volatility liquid	Negligible to severe irritation may accompany systemic toxicity; however, irritancy alone does not constitute a level 3 hazard.	Appreciable effects on coordination, perception, memory, etc., or has the potential for long-term serious injury (e.g. cancer), or may result in internal tissue damage.	Can be disposed of and contained by a cleanup procedure. Crew should don PPE according to applicable procedures/flight rules.
4 Catastrophic) (Red) Gas, volatile liquid, or fumes that are **not containable**	Moderate to severe irritancy that has the potential for long-term crew performance decrement (for eye-only hazards, there may be a risk of permanent eye damage). Note: Will require therapy if crew is exposed.	Appreciable effects on coordination, perception, memory, etc., or the potential for long-term serious injury (e.g. cancer) or may result in internal tissue damage.	Crew **cannot** contain the spill. The ECLSS may be used to decontaminate. Crew should don PPE according to applicable procedures/flight rules.

3.0 GENERAL GUIDELINES BY WHICH TOXICOLOGICAL HAZARDS AND TOXIC HAZARD LEVELS ARE ASSESSED

Chemicals and test materials to be used in experiments or other activities aboard the spacecraft can be gases, gels, liquids, or solids, which include fine particulates. They can be pure chemicals, solutions, complex mixtures, metallic alloys, etc. During processing, some materials used in in-flight experiments may undergo changes in phase (e.g. solid to liquid or gas or to vapor or fume), undergo chemical reactions to produce new chemicals (e.g. combustion), or undergo changes in concentration (e.g. dilution). Materials can be classified as organic, inorganic, polymeric, biological, radioactive, acidic, basic, neutral, oxidants, hypertonic or hypotonic. These chemical, physical and/or biological properties, together with their intrinsic toxicity, flammability, and biohazard potential, determine the hazard level of the materials. Because the range of materials is so broad, no one set of standard procedures describes how the JSC STO assesses every possible material. Some general guidelines described below are applicable for assessing most materials. Other procedures applicable to individual classes of chemicals or materials are described in Section 4.

3.1 IDENTIFYING IN-FLIGHT CHEMICALS

The JSC STO assesses the potential toxic hazards of chemicals and test materials used or contained in in-flight payload experiments, equipment, and hardware (e.g. GFE, crew escape equipment, etc.). The chemical information is provided to the JSC STO by mission managers, payload integration managers, payload organizations or investigators and others. Payload, system, and GFE hardware customers are required to submit information to the JSC STO on chemical identities, composition, physical states, concentrations, amount, test conditions and other relevant information, as specified in JSC 27472, as part of their safety data packages prepared for safety reviews.

3.2 ASSESSING THE TOXIC HAZARDS OF RELEASED CHEMICALS

The THL of a payload chemical is defined in terms of the risk to crew health from an accidental spill or leak of that chemical. It depends on the intrinsic toxicity and physical properties of the chemical without regard to physical containment. An exception to this rule is made for chemicals entrapped in a matrix that would definitely prevent their escape or rapid release. Such entrapment is considered by the toxicologist in setting the THL. A payload, system, or GFE hardware customer may propose multiple levels of containment for a highly toxic chemical to minimize its chance of release. This would not alter the THL of the chemical. It would,

however, reduce the risk to crew health. Assessment of the adequacy of containment is the purview of the PSRP, SRP, or other NASA-designated Safety Panel.

If several containers in an experiment system hold identical chemicals, it is generally assumed that the entire amount of the chemicals in only one container (the container holding the greatest quantity) could escape unless a single mishap could credibly release chemicals from several containers. Deviations in this base assumption (e.g. considering the escape of contents from more than one container/unit or assuming escape of only part of the contents from a single container/unit) may result after consultation with and direction from the appropriate Safety Panel overseeing the hardware, payload, experiment, etc. In such cases, the Safety Panel of record will formally request a toxicity assessment based on the predicted amount of chemical released and any specific modifying conditions to be considered. The STO Toxicologist will document the specific assessment criteria requested by the Safety Panel on the formal Toxicity Assessment Memorandum and/or HMST records.

3.3 ANALYZING THE HAZARD OF CHEMICAL MIXTURES

The THL of a mixture of chemicals is determined from the toxicity of the entire mixture or, if that is unknown, the most toxic component in that mixture.

3.4 ASSESSING CHEMICALS THAT UNDERGO PHASE OR COMPOSITION CHANGES DURING PROCESSING OR CONCENTRATION CHANGES AFTER MIXING

If chemicals or mixtures pose different toxicological hazards to crew members before, during, or after these chemicals are processed, all of these stages are assessed. If a liquid is to be mixed with another liquid of a different THL, then the resultant mixture is also assessed.

3.5 CALCULATING POTENTIAL ATMOSPHERIC CONCENTRATIONS OF CHEMICALS ON THE SPACECRAFT

When fine dusts, metallic fumes, gases, or vapors from volatile liquids escape in the spacecraft; these substances become airborne and could pose a toxicity concern. If the toxicity concern is for acute effects such as irritation, metal fume fever, or even

suffocation, then the assessment will assume that the released chemical would uniformly disperse throughout the module where the leak occurred. However, if the toxicity concern is for long-term effects resulting from exposure to the chemical (e.g.

exposures to carcinogens like benzene, hydrazine, or chloroform, exposure to nuisance dust like titanium dioxide or amorphous silica, etc.) toxicity will be assessed on the basis that the chemicals would uniformly disperse throughout the habitable volume**.** The THL of these chemicals will depend on the resultant modular or total cabin concentrations, which can be estimated by dividing the amount of escaped chemical by the relevant spacecraft habitable volume or the relevant spacecraft module volume. Because these values change for the ISS with changes in configuration (e.g. presence or absence of docked/berthed spacecraft and modules), the ISS cabin free volume (habitable volume) will be obtained from SSP 50623, "Joint Environmental Control and Life Support (ECLS) Functionality Strategy." This document records the volumes for ISS elements and International Partner vehicles established by the joint NASA-Russian Environmental Control and Life Support engineering community for purposes of free volume calculations and operational analyses.

There may be cases for which manned spacecraft or manned space habitats will not dock/berth with the ISS and therefore habitable volume information will not be found in SSP 50623. Information concerning the relevant spacecraft volume of dilution will, in these cases, be obtained from the most recent official design specification documents of record for that vehicle or habitat.

3.6 ESTIMATING THE RATE OF REMOVAL OF AN ESCAPED CHEMICAL

The time needed for the environmental control and life support system (ECLSS) to remove specific types of toxicants from the atmosphere depends upon many factors. These include the amount of the chemical that has escaped, its chemical and physical properties, the total volume of air to be scrubbed, the rate of cabin airflow through the various air scrubbers, the ability of the air scrubber's absorbent materials to retain specific contaminants, the mesh sizes of the air filters used to retain particulates, the relative humidity of the atmosphere, and the condensing and solution of vapors into water formed by the condensing heat exchanger (dehumidifier). Sometimes it is only possible to make a rough estimate of removal times or contaminant concentrations during and after scrubbing. The ISS ECLSS group will be consulted to assess the ability of ISS ECLSS to remove a projected escape of a large amount of chemical(s). Similarly, NASA and specific vehicle designers, builders, and operators (in the case of non-NASA vehicles) will be consulted to assess the ability of the respective vehicle's ECLSS to handle atmospheric contaminants.

3.7 IDENTIFYING POTENTIAL EXPOSURE ROUTES AND TARGET ORGANS

Of the various ways in which U.S. crewmembers or other space vehicle occupants could be exposed to an escaped chemical, ingestion (i.e., oral route) is considered least likely because they would not open their mouths to allow the chemical to enter and then swallow it. Therefore, this route of exposure is generally not assessed except in special cases. Most chemicals spilled on the skin can be readily removed; skin absorption is usually very slow. This route of exposure typically poses only minimal risk (irritancy) except in the case of highly corrosive materials, such as concentrated acids and bases and those few compounds, such as phenol, which are absorbed through the skin at a rate sufficient to cause systemic toxicity. Non-volatile liquids are routinely assessed primarily for their eye irritancy. Any liquid reaching the eye would potentially remain there for several minutes before mitigation steps could be inacted (e.g. time to destow and utilize an eyewash). Surface tension without gravity or in micro-gravity fields can allow relatively large volumes of liquid to contact the eye. However, it is assumed that closing the eyes could limit the volume of liquid in contact with the surface of the eye. Since no more than about 0.5 ml of liquid could contact the eye due to its small surface area, small or large volumes of liquid would pose similar eye hazard levels. Volatile liquids are assessed for their eye irritancy, and their vapors are assessed for irritancy to the eyes and respiratory tract and for systemic toxicity. The major concerns posed by metallic fumes, dusts, and gases are respiratory tract irritancy and systemic toxicity. Very high concentrations of dusts can pose a risk of asphyxiation. Microorganisms, animals, plants, as well as products from each of these sources such as blood cells, etc., are assessed by the Biosafety Review Board for their infectious potential.

An allergic reaction to a chemical often depends on an individual's immunological responses to such a chemical; the interaction between host and the chemical, and the magnitude of allergic response are very difficult to predict or quantify. Therefore, unless the chemical is a known allergen to the general population, the allergenic potential of chemicals is generally not considered in our toxicological assessment.

3.8 USING SMACs AND THRESHOLD LIMIT VALUES (TLVs) IN DETERMINING THLs

NASA has established 1-hour, 24-hour, 7-day, 30-day and 180-day spacecraft maximum allowable concentrations (SMACs) for approximately 50 airborne chemicals. 1000-day SMACs are established for a subset of these chemicals. Generally, these exposure limits allow minor discomfort during 1-h or 24-h exposures and no discomfort or significant risk of toxicity for longer exposures. In addition, NASA has more than 400 official and unofficial 7-day SMACs.

The American Conference of Governmental Industrial Hygienists (ACGIH) has established TLVs for several hundred industrial chemicals. The TLVs are established to protect nearly all industrial workers exposed up to 8 hours per day, 40 hours per week for their entire working life, which could be 40 or more years. A TLV value for nuisance dusts or low-toxicity particulates and metals may be established merely to protect against dust loading in the lung over many years.

NASA's THLs (see Table 1) are based on the severity of eye irritancy, systemic toxicity, potential for permanent tissue injury, and the ability of the crew and the spacecraft environmental control and life support system to decontaminate or remove that material.

Since SMACs, TLVs, and THLs are based on different criteria and are meant to be used in very different circumstances, no precise quantitative relationship exists between SMACs and THLs, or between TLVs and THLs, nor are there SMAC and TLV equivalents to the critical and catastrophic levels in the THL scale. However, there is usually a rough relationship among these three standards. For example, an exposure to a vapor rated as a critical hazard (THL=1) would have more serious toxicological effects than an exposure to the SMAC or TLV concentration of the same vapor. Therefore, if the potential spacecraft concentration of an airborne chemical is less than or equal to the TLV or SMAC, it is generally assessed as a level zero hazard (THL = 0, non-hazardous). The toxic hazard rating of concentrations greater than the TLV or SMAC will depend on the intrinsic toxicity and physicochemical properties of the chemical.

3.9 DETERMINING THE INTRINSIC TOXICITY

As discussed above, the physiochemical properties of chemicals and test materials are very diverse and their toxicities can vary greatly. Toxicity is judged by available information from reference books, computerized toxicology databases or scientific literature, or assessments performed for past HMSTs. Material Safety Data Sheets / Safety Data Sheets (MSDSs / SDSs)

and information on the biochemistry and toxicity of the proposed chemicals obtained from the payload providers or chemical manufacturers may also be used. Information on structurally-related compounds may be used to infer the toxic properties of the compound of interest. In some cases, little or no data are available for particular chemicals, and assessment requires a considerable amount of professional judgment and conservatism.

3.10 ASSIGNING TOXIC HAZARD LEVELS

After all of the above relevant steps are completed, a THL is assigned to the chemical or test material according to the definitions specified in Table 1 and following the guidelines contained in this document. If the THL of a chemical or test material cannot be readily assigned using these definitions, it is rated on the basis of the best match between the table definitions and the toxicological properties of the material. THLs are assessed on a mission-specific basis. If chemicals were assigned a THL for a previous mission, the same rating is generally applied. Occasionally, however, new toxicologically-relevant data become available or vehicle-specific parameters change that may lead to a revision of previous hazard assessments and ratings. If the chemicals being assessed have never been reviewed by the JSC STO or there is a need to change a previous THL, then a second JSC STO Toxicologist will review the new assessment. If the second Toxicologist does not concur with the new/revised assessment, then a majority of the JSC STO members will review the assessment and related data. A THL will then be assigned based on the outcome of the JSC STO quorum review.

4.0 PROCEDURAL GUIDELINES FOR ASSESSING THE TOXICOLOGICAL HAZARD LEVELS OF CHEMICALS

4.1 METALS AND METALLIC COMPOUNDS USED IN METALLURGICAL (FURNACE) EXPERIMENTS

Metals and metallic compounds can vaporize when heated to high temperatures and condense into fumes and fine dusts upon cooling. The toxic hazard level depends on the amount and toxicity of the metallic vapors or fumes produced during processing. If the investigators can provide the evaporation rates of the metals in an alloy or estimated amounts of fumes that could be generated from the alloy during processing, or if they have data on sample weight loss due to heating of the naked alloy sample, JSC toxicologists will use these data for toxicity hazard assessment. If calculated or experimental data from the payload developer are unavailable, JSC

toxicologists will use the simplified Langmuir's Law for estimation of the evaporation rate, Q (in $mg/cm^2/second$) of the metals in the alloy.

$$Q = 43.7 (M/T)^{0.5}P$$

M is the atomic weight (a.m.u.), of a given metal, T is the planned maximum processing temperature (°K), and P is the vapor pressure (mbar) of the metal at temperature T. P can be found from the literature or from a vapor pressure vs. temperature curve (see Appendix 5.01). The amount of fumes of a metal that could be generated during processing, A (mg), can be estimated as follows:

$$A = Q S t$$

where S is the surface area (cm^2) of the alloy occupied by that metal and t (seconds) is the processing time at the maximum (holding) temperature. For example, if the alloy contains 20% of metal X and has a surface area of 5 cm^2, the surface occupied by metal X is considered to be 1 cm^2. The amount of metal vapor generated during the heating and cooling phases is relatively small compared to that generated during the holding temperature, unless the holding time (at maximum temperature) is short compared to the heating and cooling time. If the holding time is relatively short, the assessment will be evaluated case by case. If experimental data are not available, the investigators are encouraged to estimate the metallic fume production of their samples using the above formula or another more appropriate equation.

Depending on the circumstances of an experiment, the temperature used in the formula above could be either the nominal maximum planned temperature or the maximum "run-away" temperature (i.e., that caused by experimental or control failure). The JSC STO generally uses the maximum run-away temperature projected by the payload developer for calculations unless directed by the appropriate Safety Panel to use an alternative working temperature (e.g. maximum nominal planned temperature) for a given experiment. If a run-away temperature is not available, JSC STO will use the maximum nominal planned temperature for calculation. Because the metal surface will decrease with heating time, and vaporization will cease after the vapor reaches saturation inside the confined space of the sample container, the value of the empirical calculation is generally greater than the amount of fume actually generated during processing.

From the calculated amounts of metallic fumes that could be generated from each metal in an alloy, the potential spacecraft cabin atmospheric concentrations of metallic fumes can be estimated in the event of their escape into the cabin as follows.

$$C = \frac{A}{V}$$

where A (mg) is the amount of fumes, V (m^3) is the spacecraft cabin volume and C (mg/m^3) is the concentration (see section 3.05). These concentrations are compared with the TLVs or SMACs of these metals, if available.

The rates of release and the decrease over time of the concentrations and the time-weighted average concentrations of vapors, fumes, or dusts due to scrubbing from the atmosphere by ECLSS can often be estimated mathematically. When appropriate, such calculations should be used on a case-by-case basis in assessing the THL of this class of airborne contaminants.

A metal fume or dust with a calculated concentration of less than or equal to one times the applicable TLV will generally be rated a THL of zero (0). A calculated concentration of non-irritating and low toxicity fume or dust of greater than one times the applicable TLV but less than ten times the applicable TLV will generally be rated a THL of one (1, critical hazard) or less. An irritating or toxic fume or dust concentration calculated to be equal to or greater than ten times the applicable TLV will generally be rated a THL of four (4, catastrophic hazard). A calculated fume or dust concentration that could pose a catastrophic hazard will be critically assessed by at least two JSC-STO toxicologists.

4.2 PARTICULATES OTHER THAN METAL FUMES OR DUSTS

4.2.1 INERT, INSOLUBLE, NUISANCE PARTICLES

Large amounts of inert, essentially insoluble, nuisance particles pose a hazard to crew members if they are inhaled and cause physical blockage of the respiratory tract or if they contact the eye surface. If the quantity of released particles of the size ranges described below reach a level in the atmosphere that could cause choking / asphyxiation, this will be classified as a physical, rather than a toxicological, hazard to the crew. Hazard assignments of non-toxic, insoluble, inert dust will depend on the amounts and physical properties of the dust and will hence be assessed on a case-by-case basis. In the absence of particle-specific suffocation data, an estimated particle concentration associated with a sudden release of particles from the hardware into the pressurized cabin that is found to be above the limits described below will be communicated to the Safety Panel, Payload Provider, and ECLS group. The Safety Panel will then determine whether or not a sudden release and/or extended crew exposure are credible. For the respiratory system, the distinction between “large” and “small” particles is determined by their ability to be inhaled deeply into the lungs.

"Large" particles: Inert, insoluble, nuisance particles of mean aerodynamic diameter >10 µm cannot be inhaled deeply into the lower respiratory tract (lungs), but large amounts could cause acute asphyxia (suffocation within a few minutes) due to mechanical blockage of the upper respiratory tract, especially the larynx. Such particles will be considered a choking hazard at estimated initial concentrations of ≥ 50 g/m^3, assuming uniform distribution in the pressurized atmosphere of the vehicle or module where the particle release has occurred.

"Small" particles: Inert, insoluble, nuisance particles of mean aerodynamic diameter ≤10 µm can be inhaled deep into the lungs and cause a slow asphyxiation (suffocation within many minutes to hours) by obstructing the deep lung and interfering with oxygen exchange. For such respirable particles, an estimated initial concentration of ≥ 13 g/m^3 in the vehicle or module where the release has occurred will be classified as an asphyxiation hazard. This estimate is based on a particle density of 1.5 g/cc, 50% deposition in the lungs, and assumes that the exposed individual has a minute volume of 10 liters/min during an exposure duration of about 360 minutes, divided by a safety factor of 2. The concentration limit will therefore differ for different minute volumes or particle densities.

Inert, insoluble, nuisance particles can also present a physical hazard for the eyes, particularly if they are hard or rough. Particles that are not excluded by the blink reflex (< 0.5 mm) may be rated as toxicity hazard level 1 (critical) eye hazards on the basis of possible traumatic eye irritation.

4.2.2 REACTIVE, TOXIC, OR SOLUBLE PARTICLES

Particles that are chemically reactive, toxic, and/or appreciably soluble in water will be assessed for toxicity on a case-by-case basis. The inhalation toxicity of these particles will depend mainly on their respirability, chemical reactivity, intrinsic toxicity, and irritancy. Generally, the smaller the aerodynamic diameter of the particles, the greater their ability to cause injury deep into the lung. Larger particles would exert their toxic effects on the upper respiratory tract. The ocular toxicity of these particles will similarly depend on size, chemical reactivity, and irritancy. Reactive, toxic, or soluble particles that are not excluded by the blink reflex (< 0.5 mm) will be assessed based on their irritancy and ability to cause permanent eye damage.

4.3 GASES

Gases stored in pressurized vessels are sometimes used in payload experiments. The potential toxicological hazard of a released gas is assessed based on the amount of that gas in the cylinder, the resultant concentration in the spacecraft atmosphere and its intrinsic toxicity or flammability. Removal rates by the ARS may be factored into the toxicological assessment. Gases can also present an asphyxiation hazard if their release results in a substantial decrease in oxygen concentration in the area. Assessments should take into account the volume of the potential hypoxic (<16% O_2) area, the rate of airflow in the vicinity of such a potential release and the likelihood that any crewmember's head could remain in the hypoxic area long enough to result in asphyxiation.

4.4 ORGANIC LIQUIDS

Liquids that are only slightly volatile or are non-volatile are assessed only for eye or skin irritancy and/or skin absorption. Volatile liquids are assessed as both liquid (eye and skin) and vapor (eye and respiratory) hazards. A chemical that is a respiratory hazard can cause respiratory irritation, or it may be absorbed from the lung into the bloodstream and cause systemic effects such as liver or kidney injury. The potential for a liquid to be a vapor hazard is determined from its amount and its vapor pressure. For example, if the vapor pressure of a liquid is low and it is not likely to escape into an inaccessible area, it is assumed that the crew would be able to remove it with an absorbent material (such as towels) before a hazardous amount of vapor is released. Therefore, it would only be a liquid hazard.

4.5 ALDEHYDE FIXATIVES

Formaldehyde (FA), paraformaldehyde (PFA), and glutaraldehyde (GA) solutions are common biological fixatives used in payload experiments. PFA is a polymer of FA and is a solid. In neutral solutions, PFA exists in equilibrium with its dissociated form, FA. All three aldehydes are very irritating to the eyes. The eye irritancy of GA at different concentrations, as reported by the Union Carbide Corporation, is shown in Appendix 5.02. The JSC flight surgeons and toxicologists agree that solutions of FA or GA at concentrations between 0.25% and 1% are level one (THL = 1) critical eye hazards. FA or GA concentrations ≥1% are level 2 (THL = 2, catastrophic) eye hazards. Although FA and GA vapors are highly irritating to the respiratory tract, the vapor pressure of dilute solutions is relatively low. Like liquid organic chemicals having low volatility (see Section 4. 4 above), it is usually assumed that if a single aliquot of dilute FA or GA solution were to escape, it could be cleaned up before a hazardous amount of vapor was released. FA

vapor at less than 0.4 ppm is assigned a THL of zero (0). FA vapor concentrations between 0.4 and 2 ppm are assigned a THL of one (1). If the potential spacecraft cabin vapor concentrations of FA are greater than or equal to 10 ppm, they could be very irritating or life threatening, and a THL of four (THL = 4, catastrophic vapor) is assigned.

4.6 ACIDS, BASES, AND BUFFER SOLUTIONS

Strong acids and bases are corrosive and can cause severe irritation and permanent damage to the eyes. Buffered solutions of acids and bases are more irritating than unbuffered solutions of the same pH. At the same concentration in water, a strong acid (e.g. hydrogen chloride,HCl; sulfuric acid, H_2SO_4), which is fully ionized to produce a low pH solution, is more corrosive to the surface of the eye than a weak acid (e.g. acetic acid, CH_3COOH), which is only partially ionized and produces a higher pH solution. However, the non-ionized (lipophilic) species, which can penetrate the intact corneal epithelium, is capable of causing damage to the inner structures of the eyes. The epithelium provides a barrier to charged ions and large molecules; however, if the epithelial layer is damaged (e.g., by a strong acid), the underlying structure is vulnerable to damage by the acid. Generally, at the same pH, weak organic acids (e.g. acetic acid) are more injurious to the eye than strong inorganic acids, such as HCl. Therefore, the potential eye hazards of acids are evaluated case by case. Appendix D contains information on the pH of some common acids and bases. If no toxicity information is available on the acid or base, the default hazard levels listed in Table 5 will be used.

Table 5

Eye Hazard Assessments Based on pH Levels

Hazard level	Acids (Inorganic)	Acidic Buffers (organic)	Bases	Basic Buffers
0*	> 3	> 5	<10	<9.5
1	2.1-3.0	2.6 - 5.0	10.0 - 11.4	9.5 - 10.9
2	≤2.0	≤2.5	≥11.5	≥ 11

*Neutral, weakly acidic, and weakly basic solutions are assessed a hazard level 0 (non-hazard) provided that they are not highly reactive, toxic or hypertonic (see Salt Solutions, below).

4.7 SALT SOLUTIONS

Hazards from salt solutions can be due to their hypertonicity, corrosiveness, or idiopathic toxicity. Hypertonic salt solutions can cause eye discomfort. Isotonic saline contains 155 mM (310 mOsm, or 0.9%) NaCl. Sea water, containing approximately 0.5 M (3%) NaCl, can produce transient, mild eye discomfort in some individuals. A salt concentration greater than 1 M or 2 Osm (twice that of sea water) is therefore rated a toxicity level one (THL = 1, critical) eye hazard. Some chemically reactive salts induce eye irritation or injury because they are strong oxidizers, (e.g. sodium hypochlorite or potassium permanganate, or reducers, e.g. hydrazine). Certain chemicals have very specific affinity for and toxicity to the eye. For example, cobalt chloride can cause injury to the eye when it is applied topically to the eye or given systemically. Because of these considerations, hazard levels are evaluated on a case-by-case basis for each solution. The reference book, *Toxicology of the Eye (W. M. Grant, 1986, Thomas Books),* is often used in assessing chemical irritancy.

4.8 CULTURE MEDIA FOR ANIMAL AND PLANT CELLS, WHOLE PLANTS AND SMALL AQUATIC ANIMALS

Culture media for living organisms or cells generally contain nontoxic salts, nutrients, vitamins, trace minerals, buffering agents, and trace amounts of pH indicator. These solutions are generally neutral or slightly basic or acidic; the osmolarity of the solutions is usually compatible with life (i.e. not strongly hypertonic). Therefore, such media are generally assessed as level zero (THL = 0, non-hazardous). A standard culture medium may contain a long list of ingredients; the name of the medium, rather than the list of ingredients may be listed in the HMST.

4.9 CARCINOGENIC COMPOUNDS

It is rare that sufficient data exist on a given chemical to permit calculation of risk levels for carcinogenesis, particularly for relatively brief exposures. Generally, the STO assumes that the increased risk of cancer due to brief exposures to most carcinogens is negligible, in the amounts generally used in payload experiments. For brief exposures, acute toxicity is generally a greater concern than carcinogenicity. If the calculated 180-d exposure concentration is less than the 180-d SMAC for this compound, then the chemical or test material would be rated a THL of zero (0). If a SMAC has not been established for the chemical or test material, then the life-time industrial exposure values (e.g. from the OSHA PEL, ACGIH's TLV or NIOSH's REL), will be used for assessments. If the calculated concentration of the chemical or test material is less than the lowest of these life-time exposure values, then the chemical or test material will be

rated a THL of zero (0). If the chemical or test material is not rated a THL of zero (0) then the following relative risk guidelines will be followed by the STO when it is possible to quantify the increased risk of cancer due to defined exposures.

Catastrophic: Increase in cancer risk greater than or equal to 1%

Critical: Increase in cancer risk of 0.01% up to 1%

Methods to quantify the risks from cancer-causing compounds are undergoing major change according to new EPA guidelines. The limitations of the linearized multistage model, which NASA has traditionally used, are being acknowledged and newer methods, such as the benchmark dose , are being explored and may be utilized by JSC STO.

4.10 BIOLOGICAL MATERIALS

All biological materials (e.g live animals, plants, cultured cells, microorganisms, viruses as well as components or derived by-products of these such as cultured cells, proteins, plasmids, etc.) will be assigned a BioSafety Level (BSL) by the Biosafety Review Board as described in JSC 63828 "Biosafety Review Board Operations and Requirements Document."

From a toxicological perspective, deoxyribonucleaic (DNA) or ribonucleic acid (RNA) samples are usually regarded as non-hazardous (THL = 0). Proteins are evaluated on the basis of their biological activity. Viral proteins obtained as genetically engineered products are generally judged to be non-hazardous materials (THL = 0). Proteolytic enzymes will be evaluated for their ability to cause eye injury.

4.11 RADIOACTIVE MATERIALS

Radioactive materials are assessed and assigned a radiation hazard level by the JSC Space Radiation Analysis Group. Their assessment will be incorporated into the HMST.

4.12 TOXICOLOGICAL ASSESSMENT OF PHARMACEUTICALS AND RESEARCH CHEMICALS

The biomedical hazard to crew member test subjects resulting from intentional administration of drugs, plasma expanders, diagnostic agents, radioactive markers, respiratory gases or other chemicals is evaluated by the IRB. The JSC STO evaluates the toxic hazard potential (mainly eye irritancy) of compounds or solutions if they should escape their containment. Gaseous compounds to be inhaled by the test subject are assessed as described in Section 4.3.

Toxicology assessments usually do not include the pharmacological adverse effects (side effects and contraindications) of medications in the crew formulary. However, unintended exposures to crew medications or pharmaceutical agents in payloads (e.g. overexposures, accidental injections, secondary exposure from reclaimed resources, etc.) are assessed when appropriate.

4.13 FLAMMABLE CHEMICALS

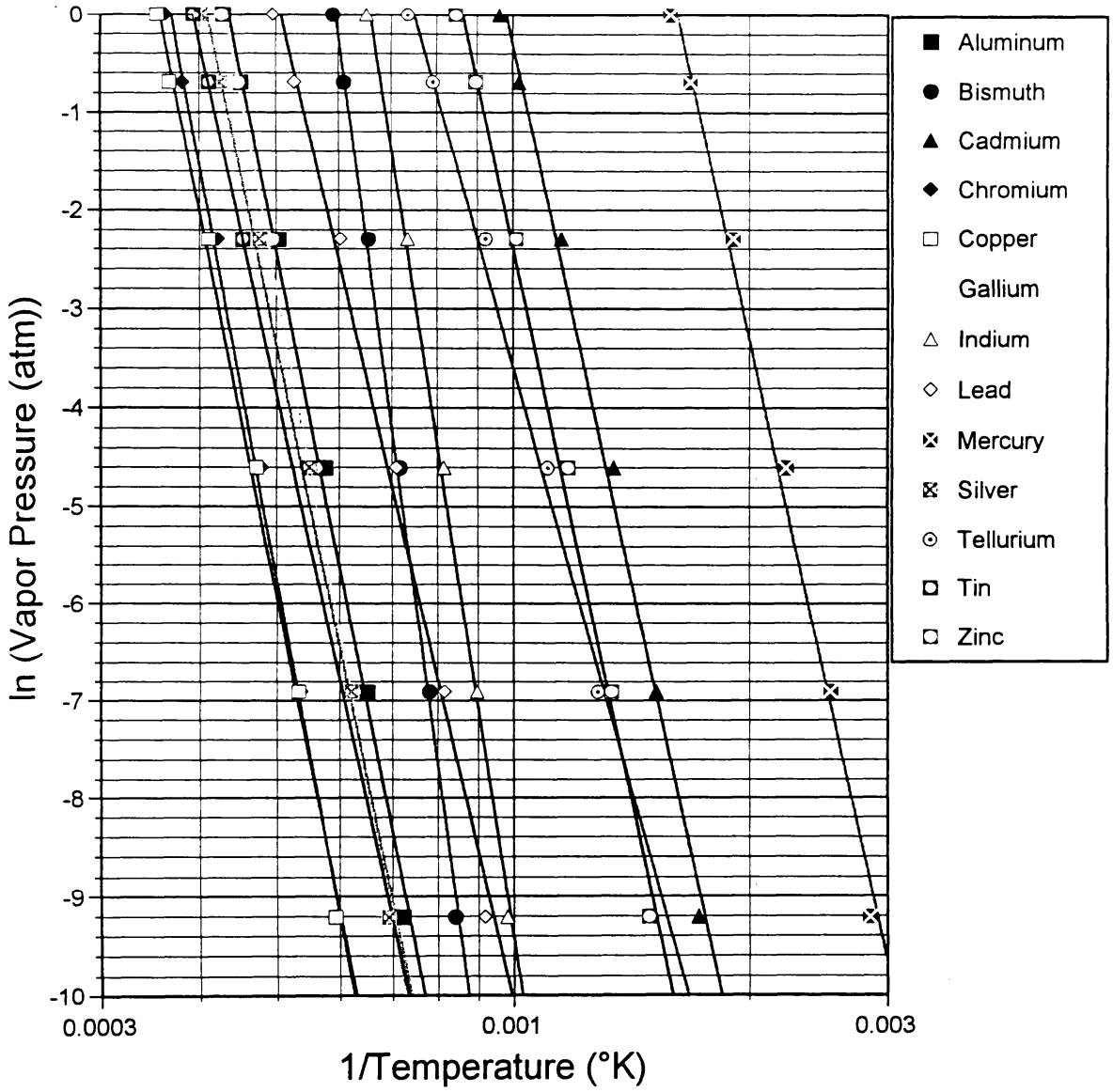
The flammability hazard of large amounts of organic materials, materials with high volatility or those with appreciable explosive potential will be assessed by the JSC Materials and Processes Branch, ES4. From a flammability perspective, metals, most particulates, aqueous solutions, and organic compounds of low volatility will usually be rated as level zero (e.g. flammability = 0).

APPENDIX A - ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
ARS	Atmospheric Revitalization System
BME	Biomedical Flight Controller/Engineer
CHX	Condensing Heat Exchanger
ECLSS	Environmental Control and Life Support System
EPA	United States Environmental Protection Agency
FA	Formaldehyde
GA	Glutaraldehyde
GFE	Government Furnished Equipment
HIV	Human Immunodeficiency Virus
HMST	Hazardous Materials Summary Table
HRPPC	Human Research Policy and Procedures Committee *(now called the IRB)*
IRB	Institutional Review Board *(replaced the HRPPC at JSC)*
JSC	Lyndon B. Johnson Space Center
STO	NASA/JSC Space Toxicology Office
MSDS	Material Safety Data Sheet
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NIOSH	National Institute for Safety and Health
OSHA	Occupational Safety and Health Administration
Osm	Osmolar
PEL	Permissible Exposure Limit
PFA	Paraformaldehyde
PSRP	Payload Safety Review Panel
RME	Risk Mitigation Experiment
REL	Recommended Exposure Limit
SDS	Safety Data Sheet
SDTO	Station Development Test Objective or Station Detailed Test Object
SMAC	Spacecraft Maximum Allowable Concentration
SRP	Safety Review Panel
THL	Toxic Hazard Level
TLV	Threshold Limit Value

APPENDIX B - CURVES OF VAPOR PRESSURE VERSUS TEMPERATURE FOR VARIOUS METALS

Curves of Vapor Pressure versus Temperature for Various Metals



APPENDIX C - SUMMARY OF THE PRIMARY IRRANT EFFECTS OF VARIOUS CONCENTRATIONS OF GLUTARALDEYDE

Summary of the Primary Irritant Effects of Various Concentrations of Glutaraldehyde

From Union Carbide's Material Safety Data Sheet for Glutaraldehyde: "Review of Toxicological Studies and Human Health Effects" (1986).

Summary of primary irritant effects of various concentrations of glutaraldehyde on the rabbit eye: six animals per group

Glutaraldehyde Concentration, % w/w	Volume Instilled, ml	Observations
5.0	0.1	Persistent severe keratitis, corneal neovascularization, severe necrotizing blepharitis and conjunctivitis.
	0.01	Delayed onset minor to moderate corneal injury with moderate to marked conjunctivitis, persisting for 2 to 3 weeks.
	0.005	Minor transient (24 hr) corneal injury with moderate to marked conjunctivitis persisting for up to 2 weeks.
2.0	0.1	Minor corneal injury at 2 to 3 days, with moderate to marked conjunctivitis persisting for 2 to 3 weeks.
	0.01	Moderate conjunctivitis of about 3 days duration, but no corneal injury.
	0.05	Minor to moderate conjunctivitis of about 3 days duration without corneal injury.
1.0	0.1	Minor corneal injury at 2 to 7 days with moderate to marked conjunctivitis persisting for up to 2 weeks.
	0.01	Minor to moderate conjunctivitis of 2 to 3 days duration without corneal injury.
0.5	0.1	Mild injection of conjunctiva of 48 hours duration. No corneal injury.
	0.01	Minimal injection of conjunctivae of less than 24 hours duration. No corneal injury.
0.2	0.1	Minimal injection of conjunctivae of 24 hours duration. No corneal injury.
	0.01	No effects.
0.1	0.1	No effects.
	0.01	No effects.

APPENDIX D - ACIDITY AND ALKALINITY OF SOME COMMON LIQUIDS

Acidity and Alkalinity of Some Common Liquids

APPROXIMATE pH values

The following tables give approximate pH values for a number of substances such as acids, bases, foods, biological fluids, etc. All values are rounded off to the nearest tenth and are based on measurements made at 25 C. A few buffer systems with their pH values are also given.

From Handbook of Chemistry and Physics, CRC Press, 65th edition, page D-150:
Modern pH and Chlorine Control, W. A. Taylor & Co.

ACIDS

Hydrochloric, N 0.1	Oxalic, 0.1N 1.6	Acetic, 0.01N 3.4
Hydrochloric, 0.1N 1.1	Tartaric, 0.1N 2.2	Benzoic, 0.01N 3.1
Hydrochloric, 0.01N 2.0	Malic, 0.1N 2.2	Alum, 0.1N 3.2
Sulfuric, N 0.3	Citric, 0.1N 2.2	Carbonic (saturated) 3.8
Sulfuric, 0.1N 1.2	Formic, 0.1N 2.3	Hydrogen sulfide, 0.1N 4.1
Sulfuric, 0.01N 2.1	Lactic, 0.1N 2.4	Arsenious (saturated) 5.0
Orthophosphoric, 0.1N 1.5	Acetic, N 2.4	Hydrocyanic, 0.1N 5.1
Sulfurous, 0.1N 1.5	Acetic, 0.1N 2.9	Boric, 0.1N 5.2

BASES

Sodium hydroxide, N 14.0	Lime (saturated) 12.4	Magnesia (saturated) 10.5
Sodium hydroxide, 0.1N 13.0	Trisodium phosphate, 0.1N 12.0	Sodium sesquicarbonate, 0.1M 10.1
Sodium hydroxide, 0.01N 12.0	Sodium carbonate, 0.1N 11.6	Ferrous hydroxide (saturated) 9.5
Potassium hydroxide, N 14.0	Ammonia, N 11.6	Calcium carbonate (saturated) 9.4
Potassium hydroxide, 0.1N 13.0	Ammonia, 0.1N 11.1	Borax, 0.1N 9.2
Potassium hydroxide, 0.01N 12.0	Ammonia, 0.01N 10.6	Sodium bicarbonate, 0.1N 8.4
Sodium metasilicate, 0.1N 12.6	Potassium cyanide, 0.1N 11.0	

BIOLOGIC MATERIALS

Blood, plasma, human 7.3–7.5	Gastric contents, human 1.0–3.0	Milk, human 6.6–7.6
Spinal fluid, human 7.3–7.5	Duodenal contents, human 4.8–8.2	Bile, human 6.8–7.0
Blood, whole, dog 6.9–7.2	Feces, human 4.6–8.4	
Saliva, human 6.5–7.5	Urine, human 4.8–8.4	

FOODS

Apples 2.9–3.3	Gooseberries 2.8–3.0	Potatoes 5.6–6.0
Apricots 3.6–4.0	Grapefruit 3.0–3.3	Pumpkin 4.8–5.2
Asparagus 5.4–5.8	Grapes 3.5–4.5	Raspberries 3.2–3.6
Bananas 4.5–4.7	Hominy (lye) 6.8–8.0	Rhubarb 3.1–3.2
Beans 5.0–6.0	Jams, fruit 3.5–4.0	Salmon 6.1–6.3
Beers 4.0–5.0	Jellies, fruit 2.8–3.4	Sauerkraut 3.4–3.6
Beets 4.9–5.5	Lemons 2.2–2.4	Shrimp 6.8–7.0
Blackberries 3.2–3.6	Limes 1.8–2.0	Soft drinks 2.0–4.0
Bread, white 5.0–6.0	Maple syrup 6.5–7.0	Spinach 5.1–5.7
Butter 6.1–6.4	Milk, cows 6.3–6.6	Squash 5.0–5.4
Cabbage 5.2–5.4	Olives 3.6–3.8	Strawberries 3.0–3.5
Carrots 4.9–5.3	Oranges 3.0–4.0	Sweet potatoes 5.3–5.6
Cheese 4.8–6.4	Oysters 6.1–6.6	Tomatoes 4.0–4.4
Cherries 3.2–4.0	Peaches 3.4–3.6	Tuna 5.9–6.1
Cider 2.9–3.3	Pears 3.6–4.0	Turnips 5.2–5.6
Corn 6.0–6.5	Peas 5.8–6.4	Vinegar 2.4–3.4
Crackers 6.5–8.5	Pickles, dill 3.2–3.6	Water, drinking 6.5–8.0
Dates 6.2–6.4	Pickles, sour 3.0–3.4	Wines 2.8–3.8
Eggs, fresh white 7.6–8.0	Pimento 4.6–5.2	
Flour, wheat 5.5–6.5	Plums 2.8–3.0	