High Risk Spacecraft Materials Offgassing

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NASA-STD-6001B, Determination of Offgassed Products (Test 7), provides the offgassing characteristics under standardized conditions for materials and assembled articles to be located within habitable spacecraft environments. Experience with Test 7 has found certain material types to be of higher risk for offgassing undesirable compounds aboard spacecraft than others. Formaldehyde and acrolein are historically high T value offgassed components of the offgassed compound target list because they have low spacecraft maximum allowable concentration (SMAC) values assigned by the JSC Toxicology Group. Carbon disulfide, benzene, acrylonitrile, and furan are additional target compounds of concern due to their lower thresholds of toxicity as determined by the JSC Toxicology Group. Materials offgassing siloxanes are also of concern due to their degradation effects on environmental control and life support system (ECLSS) components and performance. Spacecraft materials and articles defined in this manuscript as high risk were identified after examining and condensing data for these compounds of concern from approximately 3000 tests performed over 30 years. Summaries of high risk material and article types based on highest Multi-Purpose Crew Vehicle (MPCV) T values are also presented. Historical analysis shows high risk components are produced largely from test materials and articles in the general categories of electronic/powered components, foams, paints/coatings/films, adhesives/tapes, epoxy/resins, liquids/gels, Nomex® with surface treatments, markers/pens/inks, dry film lubricants, thermoplastics, hygiene items (deodorants, lip balms), and silicone rubber. These data are intended to be a resource for spacecraft materials and processes managers, designers, and toxicologists. High risk materials and articles intended for use aboard spacecraft should be tested in accordance with NASA-STD-6001B Test 7.

Nomenclature

ECLSS	=	Environmental Control and Life Support System
EVA	=	Extra Vehicular Activity
GC-FID	=	gas chromatography-flame ionization detection
GC-MS	=	gas chromatography-mass spectrometry

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ISS = International Space Station
MAPTIS = Materials and Processes Technical Information System
mg/day = milligram per day
MLW = Maximum Limit Weight
MPCV = Multi-Purpose Crew Vehicle
SDS = Safety Data Sheet
SMAC = Spacecraft Maximum Allowable Concentration
S = seconds
T = Toxic Hazard Index
TCCS = Trace Contaminant Control System
WSTF = White Sands Test Facility
°C = degrees Celsius
°F = degrees Fahrenheit

I. Introduction

NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft,[1] requires all nonmetallic materials used in habitable flight compartments, with the exception of ceramics, metal oxides, inorganic glasses, and materials used in sealed container (maximum leak rate less than 1 x 10^{-4} cm^3/sec), shall meet the offgassing requirements of NASA-STD-6001B Test 7.[2] This is of key importance when operating an existing vehicle where new missions are continually adding materials and articles and in which offgassed compounds may accumulate in the recirculating environment of the enclosed spacecraft. Total spacecraft vehicle testing examines all materials and test articles combined in the vehicle atmosphere, which compliments testing individual materials and articles according to Test 7. Total spacecraft vehicle testing was previously considered for smaller scale vehicles but poses a high risk to program schedule and vehicle design if offgas toxicity issues are identified late in the design phase.

Toxic Hazard Index (T values) are calculated using the free volume (spacecraft volume) of the habitable area of the craft under consideration. T values for each material or article offgassing test are calculated as a summation of the individual compound toxicity ratings for the offgassed components. Equations for calculating T values are found in NASA-STD-6001B and are summarized below.

Calculations of T value for a material offgas test, for 45 kg (100 lb) of material (T100) are provided in Equations 1 and 2.

$$\mathbf{T}_{material} = \sum_{i=1}^{n} \mathbf{T}_{compound_i} \tag{1}$$

where

$$\mathbf{T}_{\mathbf{compound}_i} = \frac{Offgassed\ Quantity_i \left(\frac{\mu g}{g}\right) \text{x } 45 \text{ (kg)}}{Spacecraft\ volume(m^3)} \times \frac{1}{SMAC\ \left(\frac{mg}{m^3}\right)} \tag{2}$$

Calculations of T value for an article offgas test are provided in Equations 3 and 4.

$$\mathbf{T}_{article} = \sum_{i=1}^{n} \mathbf{T}_{compound_i} \tag{3}$$

$$\mathbf{T}_{compound_i} = \frac{Offgassed\ Quantity_i(\mu g) \left(\frac{1(mg)}{1000(\mu g)}\right)}{Spacecraft\ volume(m^3)} \times \frac{1}{SMAC\ \left(\frac{mg}{m^3}\right)} \tag{4}$$

James et al. (2010) provide a description of how T values for individual compounds found in the International Space Station (ISS) atmosphere can be combined based on toxic effect.[3] The Spacecraft Maximum Allowable

Concentration (SMAC) is the maximum concentration of an offgassed product allowed in the habitable area of the spacecraft for a specified duration, and SMAC values are assigned by the NASA JSC Toxicology Office. When late design phase offgas toxicity issues are identified, it is often complex or even impossible to identify responsible T value driver materials using spacecraft offgassing measurements alone to fully address the toxic offgassing concern. Additionally, vehicle offgassing testing conducted at an ambient temperature of 23(±5) °C (73(±9) °F) does not accelerate offgassing like Test 7 does at 50(±3) °C (122 (±5) °F), allowing potential issues to arise if vehicle missions extend beyond the duration of the initial screening test. Vetting high risk offgassing materials through material level offgas testing can prevent issues prior to full vehicle testing.

In some cases, programs have implemented limited exemptions to complete material offgas testing. A weight-based exemption for the ISS volume from offgas testing was introduced in 2016 due to a history of assembled articles passing testing,[4] and because of the margin allowed by the large volume of ISS and a long history of effective scrubbing by the Environmental Control and Life Support System (ECLSS).[5] The exemption did not require testing of ISS hardware containing less than 20 lb of polymeric materials. An initial attempt was made to define a list of excluded materials, which if found in the payload, would disqualify it from the exemption. This initial non-exempt exclusion list included materials such as inks and adhesives known to be "bad actors" but was not based on an in-depth evaluation of historical high risk offgassing materials. As smaller, newer vehicles are developed, it is important to ensure a robust definition of non-exempt high risk materials exists before waivers or exemptions for these materials are considered.

This manuscript provides data on high risk materials. The authors propose all high risk materials be tested in accordance with NASA-STD-6001B Test 7. Experience with Test 7 has found certain material types to be of higher risk for offgassing undesirable compounds aboard spacecraft than others. High risk materials include high T value producing-materials and material types with a history of producing formaldehyde, acrolein, carbon disulfide, benzene, acrylonitrile, furan, and siloxanes (linear and cyclic). These compounds are commonly offgassed from historically high T value-producing materials including coatings, paints, plastics, resins, adhesives, sealants, and foams. High risk spacecraft materials and offgassed components have been identified from historical NASA-STD-6001B Test 7 testing. Experience with testing and correlating T values with individual chemical compounds indicate formaldehyde and acrolein are historically high T value offgassed components on the target list and have low SMAC values assigned by the JSC Toxicology Group due to their lower thresholds of toxicity. All NASA SMAC values, interim or published, are maintained in NASA's Materials and Processes Technical Information System (MAPTIS II).[6] Published SMAC values are also found in JSC 20584B.[7]

Formaldehyde ($H_2C=O$) is the simplest aldehyde and is a frequently used industrial chemical. It is a commonly detected low SMAC compound but is poorly absorbed by ECLSS-activated charcoal systems[8] and is catalytically oxidized by Trace Contaminant Control System (TCCS) equipment.[9] Acrolein ($CH_2=CHCHO$) is the simplest unsaturated aldehyde and is used in the production of other chemicals. Acrolein is a commonly detected low SMAC compound and a potential atmospheric contaminant with irritant and toxicity issues in spacecraft because it was found to be offgassed from the hardware of two Spacelab missions at a rate of 0.007 mg/day.[10]

Carbon disulfide, benzene, acrylonitrile, and furan are additional target compounds of concern due to their lower thresholds of toxicity as determined by the JSC Toxicology Group. Carbon disulfide (S=C=S) is used as a reaction solvent in the production of materials including rubbers, plastics, the manufactured fiber viscose/rayon composed of regenerated cellulose, and the polymeric cellulose film cellophane. Benzene (C_6H_6) is widely used as an industrial solvent. Acrylonitrile ($CH_2=CHCN$) is used as a monomer in plastics production. Furan (C_4H_4O) is a five-membered heterocyclic aromatic ether used in the production of resins and lacquers.

Siloxanes (-Si-O-Si- alternating chains) are linear or cyclic polymeric components of silicone-containing products ubiquitously found in many materials. Multiple siloxanes do not have low SMAC values but are high risk compounds because they cause ECLSS compatibility issues and degrade ECLSS systems. Siloxane offgassing was an issue for the ISS water recovery system and degraded the water separator that removes water from the breathing environment. Siloxanes were previously managed by control of personal hygiene items. Air quality monitors for ISS include siloxanes as target compounds.[11]

II. Experimental

Analysis of materials and articles was in accordance with the applicable versions of NASA-STD-6001 Test 7 using gas chromatography-mass spectrometry (GC-MS) with a gas inlet and a cryotrap and gas-chromatography with flame ionization detection (GC-FID). Calculation of T values, using 7-day SMAC values and applicable spacecraft volumes,

was in accordance with the applicable versions of NASA-STD-6001 Test 7. Data acquired at the NASA White Sands Test Facility (WSTF) for programs including NASA Space Shuttle, ISS, Extravehiclular Activity (EVA), Orion, and multiple industries were maintained in a database of all reported offgas tests performed since approximately 1991, which includes over 3000 tests. Queries of offgas quantities detected were performed in 2022 for each of the low SMAC target compounds and compiled with sample description and other test parameters. Non-target generic, unidentified components, or other compounds assigned default SMAC values of 0.1 for were not used in the search criteria. The low SMAC target compound data were sorted by offgassed amount, and the types of materials and articles were examined.

Toxic hazard index value data from approximately 1700 offgas tests performed at WSTF from 1996 to 2022 were compiled. Data were separated based on article tests with T value calculations per article and material tests with T value calculations per 45.36 kg (100 lb) of material. NASA-STD-6001B Test 7 defines the T100 value as the summation of the TC values of all offgassed constituents detected for 45.36 kg (100 lb) of material, where TC is the T value for each offgassed constituent for 45.36 kg (100 lb) of material. The Multi-Purpose Crew Vehicle (MPCV) with a volume of 15 m^3 was used for the calculations. A T100 for materials or T value of 0.5 for test articles was used when calculating the maximum quantity allowed for MPCV. The overall T rating of each material or assembled article determines the quantity of each material or the number of assembled articles that can be flown concurrently. Data were sorted from highest to lowest T value, and the 30 materials and 30 articles with the highest values were identified.

III. Results

Test materials and articles were found to be high risk based on frequent detection of compounds of concern (formaldehyde, acrolein, carbon disulfide, benzene, acrylonitrile, furan, and both linear and cyclic siloxanes) during offgas tests and/or high T values. These test materials were broadly categorized as electronic/powered components, foams, paints/coatings/films, adhesives/tapes, epoxy/resins, liquids/gels, Nomex®[7] (an engineered heat- and flame-resistant polyamide material) with surface treatments, markers/pens/inks, dry film lubricants, thermoplastics, hygiene items (deodorants, lip balms), and silicone rubber.

Offgassed compounds assigned default SMAC values of 0.1 can be strong drivers of high T values due to the low SMAC value. These include named compounds that do not have established toxicological data to assign a representative SMAC value and compounds that could not be confidently identified from the offgassed data thus were assigned a generic or unidentified component designation.

Table 1 provides a consolidation of compounds of concern query results, with “Yes” or “No” indicating whether material types generally produce formaldehyde, acrolein, carbon disulfide, benzene, acrylonitrile, furan, or siloxanes (linear and/or cyclic) at concentrations sufficient to designate the material types as high risk for any habitable spacecraft volume. Some of the compounds of concern from Table 1 were also common T value drivers in the sorted data provided in Table 2 for materials and Table 3 for articles.

[7] Nomex® is a registered trademark of DuPont Safety & Contruction, Inc., Wilmington, Delaware.

Table 1. High Risk material types that produced key offgas compounds of concern.

	7-day SMAC* (mg/m^3)	Electronic/ Powered Components	Foams	Paints/ Coatings/ Films	Adhesives/ Tapes	Epoxy/ Resins	Liquids/ Gels	Nomex® w/ Surface Treatments	Markers/ Pens/Inks	Dry Film Lubricants	Hygiene Items (deodorants, lip balms)	Silicone Rubber
Formaldehyde	0.12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Acrolein	0.03	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Carbon Disulfide	1.1	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No	Yes
Benzene	1.5	Yes	No	Yes	No	Yes	No	No	No	No	No	No
Acrylonitrile	0.4	Yes	No	Yes	Yes	No	No	No	Yes	No	No	No
Furan	0.07	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	Yes
Siloxanes	N/A**	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes

*Formaldehyde, acrolein, benzene, and furan 7-day SMACs are published in JSC-20584[7] and listed in MAPTIS. [6]. Carbon disulfide and acrylonitrile 7-day SMACs listed in MAPTIS-II[6] are interim SMACs reviewed and updated by JSC Toxicology Group in 2018.

**N/A means not applicable. The siloxanes category includes multiple compounds, both linear and cyclic, with a wide range of SMAC values, including both interim and published.[6,7]

Table 2 provides a summary of high risk material types, MPCV maximum limit weight (MPCV MLW (lb)), and T value drivers based on the 30 highest MPCV T100 values for 1700 tests performed over 20 years.

Table 2. High Risk material types based on highest Multi-Purpose Crew Vehicle (MPCV) T100 values.

MPCV T100	Material Type	MPCV MLW (lb)	T Value (T100) Driver(s)
644567.926	Marker	0.00008	Aromatic hydrocarbons
219850.686	Coating	0.00023	Hydrocarbons
204460.867	Coating	0.00024	Unidentified ketones, Formaldehyde
145891.244	Coating	0.00034	Unidentified components, n-Butyl acetate, Ethyl acetate
56235.409	Epoxy	0.00089	2-Propoxyethanol, 2-Butoxyethanol, C7 Ester
47344.275	Hygiene/Lip Balm	0.00106	Unidentified ketones
31546.434	Coating	0.00158	Ethyl acetate, Unidentified nitrogen containing compound, n-Butyl acetate, 2-propanol
30836.886	Coating	0.00162	Acrolein
19312.322	Ink	0.00259	Ethers/Alcohol/Unidentifieds, Acrolein
17899.996	Coating	0.00279	C4 Alcohol
17491.901	Liquid	0.00286	Acrolein
15237.294	Resin	0.00328	Chlorobenzotrifluorides
10664.143	Tape	0.00469	C7 Unsaturated ester
7681.501	Coating	0.00651	C10 Ketones, Formaldehyde
7282.694	Gel	0.00687	Formaldehyde
6731.527	Ink	0.00743	Unidentified ethers
6382.369	Coating	0.00783	C10 Ketones, Formaldehyde
4761.483	Adhesive	0.01050	Methyl methacrylate
4621.733	Adhesive	0.01082	Methyl methacrylate
4234.992	Thermoplastic	0.01181	1,1,1,2-Tetrafluoro-2-chloroethane
3661.765	Hygiene/Antiperspirant	0.01365	Unidentified alcohol, Siloxanes
3605.627	Coating	0.01387	C10 Ketone, Formaldehyde
3233.871	Resins	0.01546	C7 Unsaturated ester
3193.416	Resins	0.01566	Chlorobenzotrifluoride, C10 Unsaturated ketones, Benzyl alcohol
3015.639	Resins	0.01658	Dimethyl methylphosphonate
2780.114	Ink	0.01798	2,4-Dimethylfuran, 4-Hydroxy-4-methyl-2-pentanone, C8 Unsaturated ethers, Acrolein
2649.718	Ink	0.01887	Unidentified ethers
2561.294	Hygiene/Lip Balm	0.01952	Unidentified alcohol, Unidentified ketones
2544.123	Coating	0.01965	C9 Aromatic alcohol
2242.444	Foam	0.02230	Ammonia

Table 3 provides a summary of high risk article types, maximum number of assembled articles (MPCV Max. Limit (# of Articles), and MPCV T value drivers based on the 30 highest MPCV T values for 1700 tests over 20 years.

Table 3. High risk article types based on highest Multi-Purpose Crew Vehicle (MPCV) T values.

MPCV T Value	Article Type	MPCV Max. Limit (# of Articles)	T Value Driver(s)
6.091	Custom hardware	0.08209	3,3-Dichloro-1,1,1,2,2-pentafluoropropane, Acrolein
3.486	Resin	0.14341	Siloxanes
2.826	Waste containment	0.17695	Dimethyl disulfide
2.422	Electronic/powered component	0.20647	Formaldehyde
1.995	Custom hardware	0.25056	Perfluorobutenes
1.989	Electronic/powered component	0.25140	Formaldehyde
1.711	Custom hardware	0.29224	Benzyl alcohol, Unidentified components
1.548	Electronic/powered component	0.32309	Acrolein
1.492	Liquid	0.33521	Benzyl alcohol, Formaldehyde
1.426	Personal item	0.35070	Acrolein
1.357	Electronic/powered component	0.36845	Acrolein, Unidentified component
1.149	Silicone rubber	0.43502	Siloxanes
1.103	Silicone rubber	0.45336	Siloxanes
0.911	Liquid	0.54856	Benzyl alcohol, Formaldehyde
0.900	Personal item	0.55532	Methyl dioxanes, Acrolein
0.858	Custom hardware	0.58305	Formaldehyde
0.840	Waste containment	0.59547	3-Hydroxy-2-butanone, Unidentified component, Dimethyldisulfide
0.837	Custom hardware	0.59763	Formaldehyde
0.818	Custom hardware	0.61161	Unidentified components
0.785	Custom hardware	0.63700	Toluene, Trimethyl silanol
0.762	Silicone rubber	0.65605	Siloxanes
0.746	Custom hardware	0.67008	Carbon disulfide, Unidentified fluorinated component, C10 Aromatic hydrocarbons
0.728	Films (bag material)	0.68709	Acrolein
0.703	Custom hardware	0.71099	Isophorone, Acrolein, Toluene
0.673	Electrical component/cable	0.74291	Isooctyl alcohol, Unidentifieds/Generics, Formaldehyde
0.637	Nomex® w/ Surface Treatments	0.78466	Formaldehyde
0.521	Custom hardware	0.96033	2,2-Dimethyl-1,3-dioxolane
0.510	Electronic/powered components/3D printer	0.98039	Formaldehyde, Acrolein
0.483	Electronic/powered components/3D printer	1.03520	Formaldehyde, Acrolein
0.465	Custom hardware	1.07599	Acrolein, Fluorotrimethyl silane, Formaldehyde

Table 4 condenses the results of Table 1, Table 2, and Table 3 and provides a recommendation for the material and article types identified as high risk based on compounds of concern and historical high T and T100 values.

Table 4. Recommended high risk materials and articles.

Recommended High Risk Materials and Articles	Compounds of Concern (1991-2022 data)	Historical High T/T100 Values (1996-2022 data)
Electronic/Powered Components	Yes	Yes
Foams	Yes	Yes
Paints/Coatings/ Films	Yes	Yes
Adhesives/Tapes	Yes	Yes
Epoxy/Resins	Yes	Yes
Liquids/Gels	Yes	Yes
Nomex® w/ Surface Treatments	Yes	Yes
Markers/Pens/Inks	Yes	Yes
Dry film lubricants	Yes	No
Thermoplastics	No	Yes
Hygiene Items (deodorants, lip balms)	Yes	Yes
Silicone Rubber	Yes	Yes

Case studies of selected materials were conducted by surveying safety data sheets (SDS) and product information for material composition. Results are summarized below:

Hard As Nails 2103®[8] contains butyl acetate, ethyl acetate, isopropyl alcohol, nitrocellulose, adipic acid/neopentyl glycol/trimellitic anhydride copolymer, n-butyl alcohol, trimethyl pentanyl diisobutyrate, camphor, benzophenone-1 (2,4-dihydroxybenzophenone), D&C Violet No. 2 (Alizurol Purple SS). Formaldehyde was detected in the offgas test and was a T value driver but was not indicated in the SDS.

Repliset-T3-50 is a thixotropic fast curing surface replicating silicone compound containing polymethylvinylsiloxane, polymethoxyvinylsiloxane, polymethylhydrogenosiloxane, and polyorganosiloxane in addition to other ingredients which were listed in the safety data sheet. Siloxanes were detected in the offgas test and were the T value drivers. Siloxanes are prevalent in silicone compounds.

HumiSeal®[9] 1A33/521 PB25 Urethane Conformal Coating contains xylenes, ethylbenzene, methyl ethyl ketone, toluene, and 40-50% other components below reportable levels in the SDS. Acrolein was detected in the offgas test and was the T value driver but was not listed in the SDS.

Minicel L200 foam is a chemically crosslinked polyolefin foam containing polyethylene, pigment, blowing agent, and crosslinking agent. The SDS and product information were not useful in screening for target compounds. Ammonia was detected in the offgas test and was the T value driver. An unidentified blowing agent was listed in the SDS. Ammonia may be associated with the blowing agent and is informative of why foams with unidentified blowing agents are a high risk offgassing material.

Aquapon®[10] WB is a two-part epoxy bisphenol-A-(epichlorhydrin) resin. Part A contains formaldehyde, polymer with 2-(chloromethyl)oxirane, 4,4'-(1-methylethylidene)bis[phenol] and 4-nonylphenol, 2-propoxyethanol, solvent naphtha (petroleum), light aromatic, and 1,2,4-trimethylbenzene. Part B contains 2-propoxyethanol, petroleum derivatives, and crystalline silica, respirable powder. The formaldehyde-derived component of Part A may be suggestive of formaldehyde identified in offgas test data. There were more than 70 compounds detected in the offgassed atmosphere. 2-Propoxyethanol was detected in the offgas test and was the T value driver for this material. 2-Propoxyethanol was indicated in the SDSs for Part A and Part B.

[8] Hard As Nails® is a registered trademark of Coty US LLC, New York, New York.
[9] HumiSeal® is a registered trademark of Westwood, Massachusetts.
[10] Aquapon® is a registered trademark of PPG Archiectural Finishes, Inc., Pittsburgh, Pennsylvania.

Click Bond®[11] CB200 is a two-part acrylic adhesive containing methyl methacrylate, methacrylic acid, (2-propenoic acid, 2-methyl-, 2-hydroxyethyl ester, phosphate), N,N-dimethylaniline, 1,1'-(p-tolylimino)dipropan-2-ol, zinc oxide, 2-hydroxyethyl methacrylate, epoxy resin (number average molecular weight ≤ 700), benzoic acid, C9-11-branched alkyl esters, and dibenzoyl peroxide. The T value driver for this material was methyl methacrylate, which was indicated in the SDS and likely offgassed due to incomplete polymerization.

From the above survey, SDSs, and product information for various high risk materials show limited information on the presence of the compounds of concern. Safety data sheets can be used to encourage testing if any of the compounds of interest are listed, but cannot be relied upon for many compounds. Limitations of SDSs are well known and have been reviewed in the literature.[12] These include required listing of all hazardous ingredients present greater than 1% (0.1% for carcinogens) and trade secret protection of ingredients and/or composition, which lead to missing ingredients and balances not adding to 100%. Additionally, cure conditions including time, temperature, and post-cure thermal and/or vacuum conditioning affect the degree of offgassing volatile components. Materials required to cure or polymerize, including two-part adhesives and epoxies, are problematic because the degree of polymerization will affect the amount of offgassed components including unreacted monomers. Testing is necessary to ensure cured materials are safe for spaceflight.

IV. Conclusion

Enclosed recirculating spacecraft vehicles are sensitive to material or article offgas toxicity, requiring materials to be screened via NASA-STD-6001 Test 7. It is important to ensure a robust definition of high risk materials exists when full material screening is exempted. Test 7 data for over 3000 tests performed at WSTF since approximately 1991 were queried for compounds of concern. Test materials and articles were defined as high risk based on frequent detection of formaldehyde, acrolein, carbon disulfide, benzene, acrylonitrile, furan, and siloxanes. Additionally, Test 7 data for over 1700 tests were reduced and sorted by T100 values for material, and T values for articles and materials; articles with the highest values were identified as high risk.

The articles or materials that are the most difficult to meet requirements of safe air quality for crew are electronic/powered components, foams, paints/coatings/films, adhesives/tapes, epoxy/resins, liquids/gels, Nomex® with surface treatments, markers/pens/inks, dry film lubricants, thermoplastics, hygiene items (deodorants, lip balms), and silicone rubber. These data are intended to be a resource for spacecraft materials and processes managers, designers, and toxicologists. Safety data sheets and product information for various high risk materials show limited information on the presence of the compounds of concern. The authors propose all high risk materials and articles be tested in accordance with NASA-STD-6001B Test 7 as a complement and safeguard when implementing spacecraft vehicle offgas testing or vehicle specific test exemptions.

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[11] Click Bond® is a registered trademark of Click Bond, Inc., Carson City, Nevada.

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