

INTERNATIONAL SPACE STATION MATERIALS - SELECTED LESSONS LEARNED

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ABSTRACT

The International Space Station (ISS) program is of such complexity and scale that there have been numerous issues addressed regarding safety of materials: from design to manufacturing, test, launch, assembly on-orbit, and operations. A selection of lessons learned from the ISS materials perspective will be provided. Topics of discussion are: flammability evaluation of materials with connection to on-orbit operations; toxicity findings for foams; compatibility testing for materials in fluid systems; and contamination control in precision clean systems and critical space vehicle surfaces.

1. INTRODUCTION

The International Space Station (ISS) program was initiated in 1994 with the mandate to make as much use of the previous Space Station Freedom design as possible. As such, there was a heritage of requirements already in place. From this starting point, the ISS Materials & Processes function was established to control a number of safety hazards. This paper will discuss a selection of these hazards and suggest how some areas of concern could be avoided / mitigated on future human spaceflight programs.

2. FLAMMABILITY

Flammability testing methodology has been an area of significant research evaluating the effects of microgravity on the combustion process. Testing conducted and sponsored by the National Aeronautics and Space Administration (NASA) Microgravity Combustion Science Program (centered at the NASA Glenn Research Center) and the extensive work conducted in Russia, Europe, and Japan have shown that materials combustion characteristics in microgravity are quite different than those observed using the standard test methods required by the NASA, the Russian Space Agency, or the European Space Agency standards (NASA-STD-6001, P17375-082, or ECSS-Q-70-21A, respectively). As an end-user of the data, the general

microgravity combustion findings are quite comforting because they show that the long-established test conditions used for the evaluation of materials flammability are conservative. As such, when using materials compliant with the conservative test methods in our spacecraft designs, the best response to an on-orbit combustion event will be to cut power (remove the energy source) and to cut ventilation (limiting oxygen). Additionally, ground testing of flight hardware systems in normal gravity conditions is essential. Since we don't want an unexpected combustion event to propagate during ground testing, the use of the most conservative test environment from a flammability perspective is prudent. Finally, the sheer preponderance of test data under natural convection conditions will keep the use of data from the standard methods with us for many years.

One of the areas left to the control of the individual human spaceflight program is the oxygen concentration conditions of operation, which will set the oxygen concentration used for materials evaluation. For the United States Orbital Segment (USOS) on the International Space Station (ISS) program, three concentration conditions were identified. Hardware associated with the Airlock interior was evaluated against a 30% oxygen, 10.2 psia test condition. This condition was controlled by functional requirements for extravehicular activity (EVA), hardware and crew. Hardware associated with the remainder of the pressurized portion of the USOS habitable volume was evaluated against a 24.1% oxygen, 14.7 psia test condition, established by life support system requirements. Finally, all other hardware was evaluated against a 20.9% oxygen, 14.7 psia test condition, established by normal atmospheric conditions for hardware up through the phase of hardware launch.

After eight years of ISS operations, one lesson learned is that it may have been advisable for the entire habitable volume to have been designed and evaluated at a single concentration rather than two, even if the habitable volume was not expected to be operated at the elevated

levels associated with EVA. Life support systems always have levels of uncertainty in their measurement of oxygen concentration. Couple this measurement uncertainty with re-supply operations which periodically transfer oxygen to the pressurized volume on orbit, and we have had a situation where increased operational flexibility would have been available if the entire USOS had been designed and evaluated against a 30% oxygen concentration condition. Of course, the trade-off in using an elevated oxygen approach is the impact to systems design. Some parts of the ISS design may not have been able to show acceptable test results at 30% oxygen, requiring modification or significant materials changes.

3. OFFGASSING

Two situations regarding materials offgassing during the ISS program are of note. Both have involved the use of foam materials. Foam materials naturally have a higher risk of affecting spacecraft offgassing characteristics than do consolidated nonmetallic materials, because of the entrapped gas volume which can contain species from the foam manufacturing (formation) process. It is recommended that spacecraft materials groups be cognizant of the offgassing hazard with foams, and to use analytical methods which are sensitive and reliable for the detection and quantification of formaldehyde and perfluoroisobutylene (PFIB). These two materials have very low maximum allowable concentrations in a spacecraft habitable volume atmosphere. For formaldehyde, it is recommended to test materials using ASTM D5197-03, Standard Method for the Determination of Formaldehyde and Other Carbonyl Compounds in Air. No special method in testing for the presence of PFIB or other perfluoroisobutenes is recommended, only to be aware of the possibility for these highly toxic species and for reference, to please see the NASA Advisory #NA-JSC-2004-03.

4. COMPATIBILITY IN FLUID SYSTEMS

The ISS program conducted extensive evaluation of internal thermal control system coolant compatibility with the system materials of construction. This work was done not only during qualification of the system hardware design, but also later when an unexpected change in the coolant chemistry occurred during on-orbit operations. The pH of the system coolant dropped a full unit because of lack of robustness in the coolant's buffering capacity, and this decrease in pH was accompanied by corrosion concerns and commensurate

safety concerns. After years of immersion testing to understand the corrosion and performance life risks associated with the ISS internal thermal control system, we found that the preliminary electrochemical methods that we used early in our test program were actually very good and in close agreement with the long-term immersion testing. Those methods were ASTM G5, Standard Reference Test Method for making Potentiostatic and Potentiodynamic Anodic Polarization Measurements, and ASTM G59, Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements.

Most fluid systems compatibility requirements (such as in NASA-STD-6001, Test 15) are only for the evaluation of gross compatibility, where the exposure time is limited to hours, and is only intended to assure that there will be no immediate unintended chemical reaction. But for long-lived spacecraft designs, generally designed and built with severe weight and volume limits, other types of tests must be conducted to evaluate system failure risk. In general, those tests are immersion tests with the only real opportunity for acceleration being through the use of increased temperature (if an Arrhenius relationship holds for the specific condition, which is not always the case). For corrosion testing, the ISS materials team developed additional confidence in the use of cyclic potentiodynamic polarization scanning for quickly evaluating corrosion risks.

5. PARTICULATE CONTAMINATION CONTROL

The habitable volume of ISS has a surface cleanliness requirement of "visibly clean – sensitive", as defined by NASA standard SN-C-0005, Contamination Control Requirements. Essentially, this requirement means that pressurized element surfaces have to be clean enough to exhibit no visible particles at an arm's length distance and under reasonably bright illumination. The requirement is for both vehicle and crew safety. Although this requirement has been in place since the beginning of the ISS program, verification of compliance can be a problem. Complex systems built with intent to absolutely minimize volume can lead to inspection difficulties. The cleaning process itself can be tedious and time consuming, and consequently an impact to cost and schedule. Based on problem areas that have been observed during the ISS program, it appears that the root cause in many of these situations lies in the intent to do a thorough cleaning at the end of all hardware processing. From ISS experience, saving the cleanup task to the end of the manufacturing flow is not effective. "Clean as you

go” is the only way to go. Cleaning at the end of each shift is a good practice, but these regular cleanings are especially critical prior to hardware manipulations or reorientations. Hardware movements will redistribute contamination, sometimes from removable/cleanable areas to inaccessible areas.

It is also important to be on the lookout for particulate traps in the design configuration which may require specialized tools or even some disassembly in order to be cleaned and inspected thoroughly. Match drilling operations have been found to contribute the most hazardous particles, metal shavings. So the use of particulate generating processes at the assembly level must be closely scrutinized for all possible locations where particulate could be distributed. Despite the inevitable schedule pressures, the discipline to perform regular cleaning operations and prevent contamination redistribution will pay off in the end.

Flexhoses need special attention if precision cleaned. Most fluid systems on ISS are cleaned to Level 200A or 300A per MIL-STD-1246, Product Cleanliness Levels and Contamination Control Program. The convolutions form natural traps, not only for particulate and nonvolatile residue but also for the cleaning fluid (which may itself be an unacceptable contaminant in the fluid system). Flexhoses should be cleaned and verified clean in a vertical orientation. For hoses of reasonably large dimension (>2.5 cm), the cleaning and verification test fluid should be applied internally through use of a high pressure nozzle to the entire length of the flexhose.

Most importantly, particulate contamination control is a matter of training. All personnel working around precision cleaned hardware must be sensitive to avoiding the costs and risks associated with finding a contamination problem that could have been dealt with through up-front assessment and reasonable discipline.

6. ACKNOWLEDGEMENT AND SUMMARY

All work described in this paper was conducted under NASA Contract NAS15-10000, International Space Station Integration and Operations. The ISS Vehicle team is recognized for their efforts in keeping safety as our chief concern. From a materials perspective, foremost recognition goes to Dr. Mike Pedley, the ISS Materials and Processes system manager from 1996 through 2006.

The sheer size and multi-system complexity of the ISS program provided a number of opportunities for the materials community to learn, dealing with issues from the earliest requirements definition phase through our current sequence of the final assembly flights and the operations phase. It is hoped that this selection of lessons learned will have value to those involved with our continued forays away from our planet and into the black.