Hardware Odor Containment Validation Methodology Development Using Gas Analysis and Controlled Human Evaluation Methods

Thomas B. Handley, *White Sands Test Facility*
Susana A. Harper, *White Sands Test Facility*

Odor Containment Evaluation Methodology

The issues associated with the control of odor on spacecraft have been mitigated by screening materials, processing wastes, and/or segregating wastes. The spacecraft designs for the Orion Program make the processing of wastes impossible and the segregation of wastes very difficult. This issue was identified early during the design of the spacecraft, thus a requirement for the odor containment of waste odors was developed. The requirement is for odor containment hardware to contain the odors for the potential maximum duration of the missions—i.e., 90 days. The program funded the development of hardware to contain the odors and development of a methodology to validate this hardware. While developing the methodology for evaluation of odor containment, NASA addressed the following technical issues: use-scenario packaging and conditioning; gas analysis; control comparisons; waste volume to spacecraft free volume simulation; and a controlled human evaluation.

Use-Scenario Simulation

To accurately evaluate the odor containment properties of the hardware, testing must closely simulate the actual use conditions. The use-scenario packaging and conditioning were scrutinized such that the configuration and the amounts of wastes could be simulated to obtain results that are as close to representing the actual mission as possible. The use-scenario packaging and conditioning included the odor containment hardware, waste identity, waste quantity, waste preparation, waste packages, waste prepackaging, and environmental conditions. The odor containment hardware evaluated must be in the end-use configuration and contain all of the materials that the end-use hardware will contain. The identity and quantity of the waste to be contained in the hardware must be known and duplicated. The quantity of waste used in the evaluation should be the maximum anticipated quantity to be generated such that the worst-case scenario is represented. If the waste will be prepared in any way, these procedures must be known and duplicated. The way that any packages will be opened, used, and then configured and sealed prior to being placed into the hardware must be known and duplicated.

It is possible to be interested in testing an entire odor containment system. This could include various types of waste, primary containment, secondary containment, and, finally, final containment. In this case, the waste must be controlled inside of the hardware in such a way that it simulates multiple disposal activities. Simulation must incorporate all final waste conditions from the initiation of test. Configuration must ensure that primary and potential secondary containment of deposited waste simulates use conditions inside of final containment vessel. The evaluation of both primary and final containment will be evaluated as a whole in this system test. Rigor of primary containment seals and potential failure during additional disposal activities should be considered as a risk to containment system. The entire test configuration will be encapsulated in a non-permeable chamber in which any permeated volatiles can be fully contained and analyzed (see figure 1).

The environmental conditions in the spacecraft—in particular, temperature and relative humidity—must be known. The set conditions for evaluation of the hardware should use the worst case. Temperature is a strong driver for diffusion with worst cases being defined as the hottest the temperature could be. Relative humidity also can affect material barrier qualities with the worst-case condition being defined as the most humidity that could be present. Selected worst-case conditions are simulated and maintained inside of non-permeable vessel containing waste test configuration.

Odor Breakthrough Determination, Part 1: Gas Analysis

The toxicity of the test atmosphere generated and the determination of the odor breakthrough time must be predicted by gas analysis of the test atmosphere. To determine the odor breakthrough time, it is necessary to monitor the test atmosphere using an analysis method. The analysis methods were selected such that any potential volatile organic or inorganic chemical present in the test atmosphere could be identified and quantified in the presence of a complex matrix. The analysis method to determine the odor breakthrough time was selected such that small amounts of chemicals being released into the test atmosphere could be separated and quantified quickly. The identities and quantities of the chemicals being evolved from the waste were also determined to have significant importance for the characterization of the chemicals responsible for the odors, and how the chemical

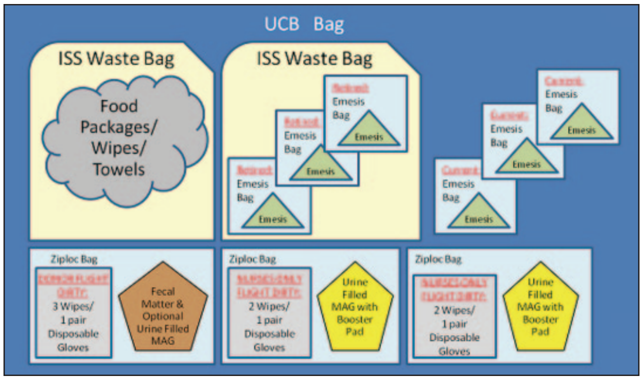

Fig. 1. *Urine containment bag Block0 waste bag configurations.*

composition and odor changed over time. The analysis data must be rigorous enough to be used to evaluate toxicity of the test atmosphere accurately such that they meet the requirements detailed in 21 Code of Federal Regulations Part 50-Protection of Human Subjects.

Odor Breakthrough Determination, Part 2: Control Comparisons

The use of control comparisons was identified as a crucial part of the evaluation. The identification of the odor breakthrough time must be predicted as a result-evident increase in volatiles in chamber indicating breakthrough identified by gas analysis and then confirmed through human evaluation. Nonetheless, most nonmetallic materials off-gas chemicals into their environment, thus the gas analysis must be able to discriminate between chemicals that are off-gassing from the containment hardware itself from the chemicals from waste odor chemicals permeating through the packaging and indicating breakthrough. To make the odor breakthrough determination from the analysis results, a comparison sample containing all the clean and empty hardware and all primary and secondary containment material must be evaluated in parallel schedule and conditioning to the hardware with the waste. The comparison sample must also have the same configurations of the hardware and prepackaging materials, and must be environmentally conditioned in the same fashion as the hardware with the waste. This can be termed the "control configuration." The general value to use as a guideline in determining odor breakthrough is when the difference in total hydrocarbons between the control and waste configurations is greater than or equal to 2 parts per million (ppm).

Waste Volume to Spacecraft Free Volume Simulation

The waste volume to spacecraft free volume governs the concentration of the chemicals being evolved from the waste and eventually released into the breathing zone of the crew. If the odor breakthrough time will be representative of the actual use conditions, this parameter must be simulated so that the controlled human evaluation is evaluating what the spacecraft crew will be experiencing. The simulation of the waste volume to spacecraft free volume is accomplished by determining the craft free volume, waste volume, and available test chamber volumes. The test chamber volume is selected such that the ratio of the waste volume to container volume is the same or greater than the ratio of the waste volume to spacecraft free volume. The result of the ratio for the waste volume to test chamber volume being greater than the ratio of the waste volume to spacecraft free volume is that the simulation will have greater concentrations of chemicals in the test atmosphere than would be anticipated for the spacecraft atmosphere. The greater concentrations in the test atmosphere allow for the test atmosphere to be diluted to the anticipated concentration for the spacecraft prior to being provided to the controlled human evaluation.

Odor Breakthrough Validation and Assessment; Controlled Human Evaluation

The controlled human evaluation was determined to be of significant importance due to the inability of any analysis method to rate a test atmosphere according to the quality of the odor. Odor is an ability of living organisms and the quality of an odor is a subjective and individual experience that cannot be duplicated by analysis or algorithm. Special considerations must be implemented when using human subjects to obtain information. The population of human subjects used must be great enough to allow for statistical comparisons and is typically randomly selected; a baseline odor sensitivity test is conducted to ensure that the subject has sufficient sensitivity to a range of smells.

The strategies used to obtain information from the individual human subjects are also of significant importance. The human subjects must not be allowed to influence each other, so they are exposed and questioned privately and then requested to not discuss the experience. The way that the questions are asked and how rating scales are presented are of significant importance. Semantic differential research methodologies were used to develop a semantic differential scale (figure 2).

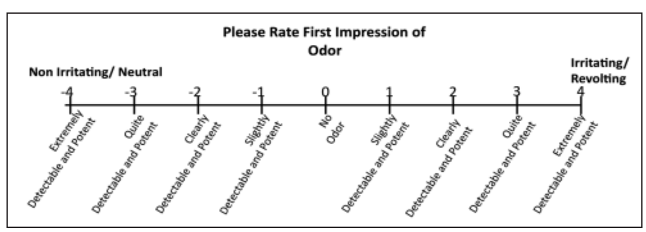

Fig. 2. *Odor containment semantic differential scale.*

The validation and assessment of the odor breakthrough time uses five human subjects. This number is sufficient to have confidence that the odor from the waste is being

Hardware Odor Containment Validation Methodology Development Using Gas Analysis and Controlled Human Evaluation Methods

continued

detected or not detected by the human subjects. The potential validation and confirmation of odor breakthrough is based on exposure to, and comparison between, the control configuration and the waste configuration. Human panel members compare odors and confirm that an odor difference is detected as described above. When the quality of the odor and assessment of potency in the test atmosphere over time after breakthrough is desired, continued evaluation at strategic time intervals is recommended to account for individual differences from human subject to human subject. A larger group of evaluators is recommended for post-breakthrough odor potency monitoring and evaluation. It was determined that six to 10 human subjects would supply enough information such that the quality of the odor could be confidently described as time passed after breakthrough. The methodology is designed to determine the maximum amount of time a device will contain odor in a desired configuration. The odor acceptability will be determined by human test subjects at intervals and is recommended to be monitored for the length of time simulating the duration of the mission. The test, however, can be halted at the point the system owners feel that odor potency is not acceptable. The test results from developed methodologies are summarized in the following section.

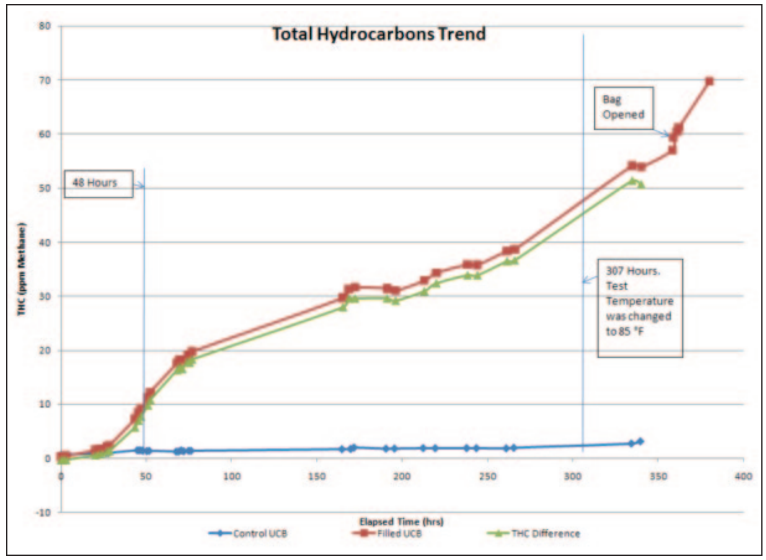

Fig. 3. Total hydrocarbon content analysis results.

Odor Containment Evaluation Methodology Conclusions

The total hydrocarbon content analyses on the filled urine containment bag and control urine containment bag test atmospheres show divergence of the content of the two test atmospheres, indicating odor breakthrough (figure 3). Rigorous chemical analyses performed for toxicity evaluation supports the total hydrocarbon content results.

The human panel evaluation unanimously confirms that the chemical analyses were in fact detecting odor breakthrough at the 2 ppm delta (figure 4). Data validated that the developed methodology produces the desired information. The rigorous chemical analysis reveals much about the odors. Comparisons of the description of the odors to the chemical analyses that correspond to the times of the human panel evaluation clearly show the detection of many chemicals that are known to have strong odors. The challenges associated with the Orion Program and future programs are not insurmountable. With a proven methodology to evaluate odor containment properties of materials and components, the hardware can be challenged, developed, and eventually perfected.

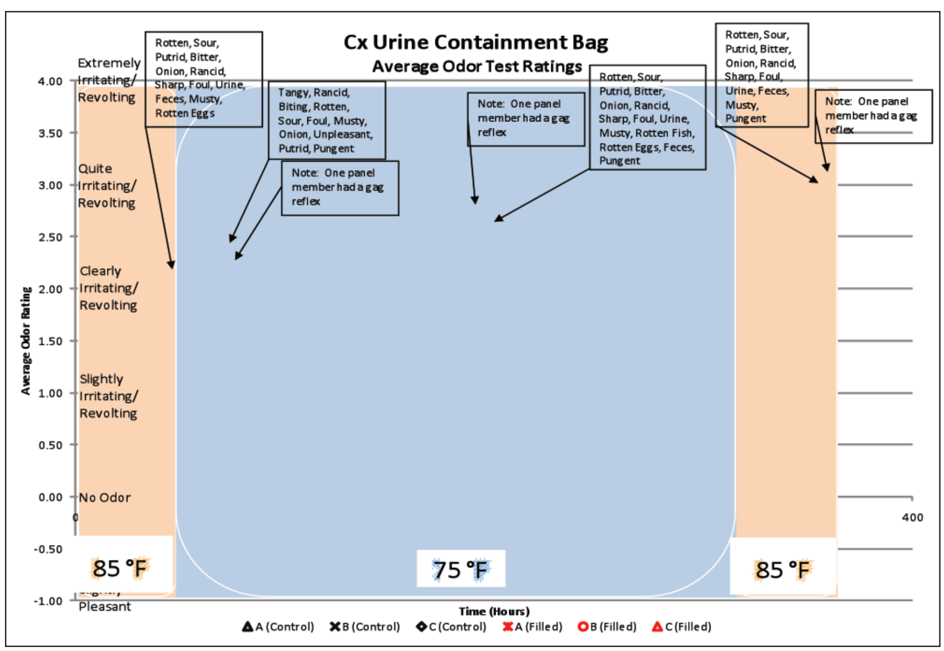

Fig. 4. Odor assessment results for control and filled urine containment bags.