

SPACE STATION FREEDOM
TOXIC AND REACTIVE MATERIALS HANDLING
WORKSHOP

November 29 - December 1, 1988

PANEL SUMMARY AND RECOMMENDATIONS

December 19, 1988

N91-15931

INTRODUCTION:

Teledyne Brown Engineering (TBE) was tasked by several NASA Organizations to organize, conduct and document a workshop devoted to Space Station internal contamination issues. These organizations included the Office of Space Station (Code S), the Office of Space Science and Applications (Code E), and Office of Aeronautics and Space Technology (Code R). Representatives from NASA, NASDA, ESA, Space Station contractors and the private sector were invited to attend. Approximately 200 individuals attended, representing a broad spectrum of industries and organizations.

The official program was divided into several sessions which addressed the following topics:

1. Past Flight Experience (Skylab and Spacelab missions)
2. Present Flight Activities (Spacelabs and Soviet Space Station Mir)
3. Future Activities (Materials Science and Life Science Experiments)
4. Space Station Capabilities (PMMS, FMS, ECLSS, and US Laboratory Overview)
5. Manned Systems/Crew Safety
6. Internal Contamination Detection
7. Contamination Control - Stowage and Handling
8. Contamination Control - Waste Gas Processing

In order to document and summarize the findings of this workshop, TBE appointed a panel consisting of the following members: Dr. Bonnie J. Dunbar (NASA/JSC), Dr. Martin Coleman (NASA/JSC), and Mr. Kenneth Mitchell (NASA/MSFC). The panel facilitated discussion during the sessions and summarized these discussions and resulting recommendations at the completion of each days activities.

This report is a compilation of issues, concerns, and other topics which arose during the workshop. It is divided into three sections. In the first section, Space Station design assumptions are discussed. The second section discusses issues and concerns as they relate to (1) policy and management, (2) subsystem design, (3) experiment design, and (4) internal contamination detection and control. The last section summarizes the recommendations generated during the three day workshop. Most of the concerns and recommendations summarized in this report were not the result of single sessions, but appeared as recurring themes during the workshop.

The panel believes that the workshop was very worthwhile and that serious decisions must now be made. *We believe that, in order to avoid costly redesign in the future, the issues and concerns identified in this report should be receiving maximum attention by the Space Station Project in its early engineering development of subsystems and experiment facilities.*

SPACE STATION DESIGN ASSUMPTIONS:

Space Station *Freedom* design is currently comprised of one habitability module and of three laboratory modules; one each from the United States (USL), Japan (JEM), and the European Space Agency (Columbus). All four of the modules are interconnected by nodes. The experiments which will involve the bulk of the hazardous materials to be handled represent two disciplines: life sciences and materials sciences. While both of the disciplines have flown on prior Skylab and Space Shuttle missions, the Space Station will include many new *in situ* sample preparations. For the materials sciences, this includes a family of liquid etching acids for which we have no prior space flight experience. In the field of life sciences, although we have previously "fixed" samples on orbit, both animal dissection and cell cultures will introduce new experiment materials and operations to the Space Station.

There are several fundamental design and operations concepts which are applied to terrestrial laboratories and which can be considered relevant to a space-based facility. They are the following: (1) the Space Station *Freedom* is an international laboratory which should be governed by well understood and consistent safety policy/guidelines, (2) facility design is the first line of protection against hazardous situations but operations of the design must also be well understood, (3) if the facility design/operations fail, then appropriate detection should be in place to announce the hazard to the crew, (4) there must be preplanned on-orbit methods to recover and handle wastes, including accidental in-cabin spills, (5) procedures and hardware must be present to medically treat crewmembers, and (6) the wastes must be transported safely to the ground for further disposal.

The handling of toxic and reactive materials aboard the Space Station will be particularly challenging for the following reasons: (1) The Station is nearly a closed environment-- rapid evacuation is not possible, (2) the laboratory researchers must habitate a volume intimately connected to their laboratory, and (3) materials science and life science experiments will be conducted in the same laboratory; this does not occur in ground based laboratories.

There are presently three Station subsystems being designed which are involved in the detection and/or control of toxic and reactive materials: the Environmental Control and Life Support System (ECLSS), the Process Materials Management Subsystem (PMMS), and the Fluid Management System (FMS).

The primary U.S Lab subsystem being designed to interact with hazardous/toxic and reactive materials is the PMMS. It consists of the following elements.

- Process Fluids Storage and Distribution
- Chemical Storage
- Materials Transport
- Ultrapure Water Management
- Waste Materials Handling
- Leak Detection
- Crew/hardware decontamination
- Vacuum Venting (high quality source and waste gas vent)

The Space Station ECLSS provides trace contaminant gas removal from the crew's breathable atmosphere as well as monitoring of atmospheric contaminants (gases and particulates). These trace gases are primarily generated from metabolic

processes of the crew and electronics equipment off-gassing. The PMMS and/or the payload will provide containment and control for their non-standard substances-- not the ECLSS.

The FMS interacts with the PMMS in the vacuum venting of waste gases and the resupply of fluids (water, nitrogen) to the U.S. Lab. The allowable waste gas constituents are being defined to the work packages and the International partners through a Level II FMS working group.

FINDINGS AND CONCERNS

POLICY AND ORGANIZATION

1. THE NEED FOR A SAFETY ATTITUDE

Although engineering solutions are being designed to handle toxic and reactive materials on a routine basis, we found a lack of emphasis on both operations and the exploration of accident scenarios. Clearly, the designers must prepare for the worst in addition to designing to prevent it. Specifically, more emphasis needs to be placed upon approaches to "in cabin spills" resulting in the cleanup of hazardous or toxic materials, and the isolation of contaminated modules. This was well reinforced by several of the private sector presenters at the workshop. Additionally, the responsibility for these activities should be assigned to an organization. There appeared to be no one who believed that to be in "their charter". *The safety attitude is germane to any research program. It is a day to day responsibility for everyone involved.*

2. THE NEED FOR A UNIFORM SAFETY POLICY

This workshop was organized for all Space Station participants. However, ESA sent one representative who was not a professional safety employee and NASDA sent two representatives, but their safety policy was not voiced. From the discussions which occurred, we concluded that the Safety Policies which we believe are in effect for Space Shuttle and which are being developed for Space Station are not being communicated to our international partners. As a matter of information, the ESA representative informed the group that ESA assumed that NASA would dictate safety requirements to them, and had not yet taken a formal look at safety in the Columbus module development. Implementation of safety policies in the US module alone will not protect a crew from catastrophic events.

The Station must be viewed as one resource operating under one standard of Safety, for both experiments and subsystem development. Reference should be made to the NRC series on "Prudent Practices for Handling Hazardous Chemicals in Laboratories". Additionally, the question of who is vested with final responsibility for safety of the Station's internal environment should be clarified.

3. THE NEED FOR A MATURE SAFETY ORGANIZATION

During the workshop, both Space Station subsystem designers (FCLSS, FMS, PMMS), and experiment developers stated that their hardware designs were dependent upon clearly articulated safety requirements. Without specific design requirements and access to past flight experiences, hardware is subject to later redesign. However, the Space Station Safety organization is still being developed and not in the position of advising either system designers or experiment developers (particularly material processing furnaces) on such items as fault tolerance, triple containment, etc.

Although the JSC Safety Boards have addressed many of these same questions with respect to the Space Shuttle/Spacelab subsystems and payloads, most of these designers do not have access to those boards. In many cases, the designers, by not being familiar with past flight experiences using similar designs, were "re-inventing

the wheel". For example, the PMMS and FMS are at a point when serious design decisions must be made (these are discussed later). The early involvement of flight safety personnel with facility designers/experimenters should resolve many issues, avoiding serious redesign of equipment.

One suggested solution is to utilize the safety organization at NASA/JSC for an interim period of time, so that timely response is available to the hardware designers. However, with the advent of the Space Station Safety boards, continuity should be maintained. The utilization of different NASA safety organizations should be virtually transparent to a user of either Shuttle or Space Station. Many payloads will fly on both. For example, the furnaces which are being developed by ESA, NASA, and many US users for Space Station will fly first on Spacelab flights.

Another suggestion is to combine these NASA safety organizations, thereby reducing the number of safety interfaces for a user, and providing consistency and a past flight experience data base to the evaluation of subsystem designs. Consistent safety policy is important for all space flight elements.

Members of the workshop suggested that until more access to the Safety Organization is available, the Space Station program should provide safety related design requirements in a "Users Manual". This manual should provide hardware design options and clearly define such concepts as "two fault tolerance, triple containment and hazard control". Furnace designers wish to understand the concept of "credible failure" and how procedures, functional features (e.g. door interlocks, etc) and negative pressure operations contribute to their design. Communication of past and present flight experience related to safety and facility designs is essential. Designers should also have access to Spacelab Hazard Analyses and Safety Compliance Data. For many users, the need for this documentation is now.

Unless the development of the Safety organization can be expedited, both the station schedule and cost are at risk.

4. THE NEED FOR BETTER COMMUNICATIONS

Better communications are required across the board: Between the international partners, between the NASA Centers, between the contractors and NASA, between NASA and industry, and between all elements and the flight operations organizations. The Office of Space Flight (Code M) was not an official organizer of this workshop but is responsible for flight crew training and safety. Future discussions regarding operational experiences and approaches to on-board safety may be directed to the Flight Crew Operations Office (FCOO) at NASA/JSC.

FCOO has several internal Astronaut organizations expressly established to develop an early working relationship with flight hardware designers: the Shuttle Mission Development Group, the Space Station Group, and the Science Support Group.

Communications must be open, frequent, and along more clearly defined paths among Centers and other organizations. Our past flight experience with STS-51L and the emphasis that the Rogers Commission placed on communications must not be "lessons learned" which are lost. This workshop was believed by all participants to be an important first step in that direction.

5. COMMONALITY

The question of commonality, which has arisen in other system designs affecting the international modules, is even more important in the arena of safely handling toxic and reactive materials. There is not a common design approach for the handling of these materials and it is not apparent that the international partners are actively addressing the potential problems. Again, the agency is faced with defining safety design criteria and then implementing these as requirements. An important question is how NASA will task these requirements to the partners and oversee their implementation. The Space Station crews must not be trained to safe three different system designs. The lack of commonality between safety systems is a well known contributor to industrial and aircraft accidents.

STATION SUBSYSTEM DESIGN

6. UTILIZATION OF GROUND BASED LABORATORY SAFETY FEATURES

Procedures and data generated by ground based laboratories is an excellent resource data base for understanding and implementing procedures/hardware for the safe handling of toxic and reactive chemicals. NASA should not re-invent the wheel. One representative from the semiconductor industry stated that we were about 5 years behind industry in our approach to the problem. At the same time, users stated that new safe handling procedures which NASA may develop for this more restrictive environment may have commercial applications on the ground. More interaction with both industry and commercial laboratories should be pursued.

7. NUMBER OF ECLSS STATIONS FOR MONITORING TRACE GASES

The total number of ECLSS locations for monitoring trace gases in the cabin atmosphere needs to be evaluated with respect to the entire monitoring systems in the USL, JEM, and Columbus. Currently 7 locations are baselined in the Space station configuration with the international modules attached. This may not be enough, particularly if early "leak warning" needs to be annunciated to the crew. The PMMS plans to detect at the rack level, but it is not clear if these will be experiment specific or general detectors.

8. PMMS DESIGN LIMITATIONS

As designed, the PMMS proposes to collect a variety of both life science and materials science wastes. In this respect, it has a much broader scope than any existing ground based laboratory or industry. However, it has limited the types of waste it will handle. The limitations to experiment development are not clear. Experiment designers need this information in order to proceed. Questions remaining include which wastes are regenerable (besides the water recovery feature) and what waste storage systems will PMMS provide for returning hazardous waste to earth via the logistics elements.

The current PMMS baseline design has a centralized waste material approach. Trades are to be performed on alternate approaches: decentralized storage of

waste by PMMS versus user provided waste storage at the rack level. Current Shuttle/Spacelab operations do not use a common waste collection system. Chemicals (e.g. varieties of acids) used in the etching of metrology specimens might be better handled within the glovebox and stored in a separate container for transport back to the ground. The mixing of acids, cell cultures, fixatives, and etc presents an infinite matrix of design requirements for a disposal system. Since Space Station facilities are being designed now, there is a definite need to identify their interfaces and requirements for waste disposal. As an added note, neither the JEM or Columbus have an interface with the PMMS, which may result in at least three methods for storing and transporting experiment wastes. Experiments which may design their interfaces for the US lab may find that although they have access to the ESA or Japanese labs, their experiment interfaces are incompatible.

Finally, NASA should review certain design features of the PMMS using past experience with liquid transport systems (e.g. Shuttle/Spacelab and Skylab). For example, it is not clear how the wastes from a glovebox operated experiment are actually introduced to the PMMS water lines in a micro-g environment; how residue left in containers are handled; how wastes which may have deposited on the interior of the large volume gloveboxes are collected for disposal, and how the task for predicting multi-chemical reactions in a "holding tank" will be accomplished, particularly if the chemicals used in metrology or cell fixation today may not be the same ones we use in 10 years.

9. ISOLATION OF THE ECLSS AVIONICS AIR COOLING LOOP

The isolation of the avionics air loop from the equipment containing toxic chemicals could be a design issue. More investigation of the user requirements for cooling and the hazards associated with the equipment requiring cooling must occur.

10. HUMAN FACTORS ARE AN IMPORTANT ELEMENT IN SAFETY DESIGN

Facilities should consider the maintenance and repair capabilities of the crew on orbit, particularly if a system is critical to continued safe functioning of the station. Hazard detection and adequate alerts to the crew are essential. As illustrated by both the Skylab and Shuttle crewmembers, alerts should identify both the location of the hazard as well as the type.

11. CONTINGENCY PLANNING IS ESSENTIAL

Contingency planning should be an essential element of hardware design. Unexpected events should be expected and planned for. It was recommended that procedures and hardware be developed for in cabin spills (for both subsystem and experiment failure) and that hazardous payloads be manifested far from exits. Participants felt that locating the emergency shower or an alternate decontamination system in the node would provide better isolation of a crewman from a spill and allow more ready access from the ESA and JEM modules.

12. DESIGN OF A CREWMEMBER DECONTAMINATION SYSTEM

Ground based laboratories usually utilize emergency showers and eye wash systems to rapidly remove contaminating materials from the body. Space Station has located a hygiene shower in the U.S. Laboratory which will also be used as an emergency shower. Several aspects of this approach must be evaluated: (1) will a shower work as effectively in a zero G environment as it does in one G? (2) what are

the ramifications of detoxifying a crew member in the module which must be isolated? (3) will crewmembers working in other modules having no similar system be able to use the system and won't cross contamination become a problem? and (4) what other neutralizing systems and treatment are also readily accessible?

Ground based showers use a deluge system and rely on a large volume of water to dilute contaminants on the body and deliver them away from the body. In zero G, such a shower would require immediate storage access and a large vacuum to pull water from the body and surrounding shower surfaces.

13. SPACE STATION SMAC VALUES MUST BE EXPEDITED

The spacecraft maximum allowable concentration (SMAC) levels for trace contaminants in the cabin atmosphere have not been defined for space station. Current designs use shuttle data for a 10 day mission. NRC is under contract to JSC to develop design criteria. The ECLSS and the PMMS need this data as soon as possible in order to design control and monitoring systems.

14. DESIGN VERIFICATION ABOARD THE SHUTTLE

Many of the new fluid handling systems represent new technologies and will receive their first flight test once installed on the Space Station. Consideration should be given to flight verification of some of these newer systems prior to implementation on the station. ESA is currently using Spacelab flights for Columbus subsystem and experiment development. Flight test should ideally occur in 1990 to support development schedules (CDR) but the lack of access to the manifest and the estimated costs (\$44M/ flight for ECLSS) are presently formidable barriers.

15. DESIGNING AIR FLOWS FOR SAFER OPERATIONS

In microgravity, it may be beneficial to consider designing air flows to give directionality to the movement of fluids in the Space Station modules. In ground based facilities gravity is relied upon to pull hazardous and toxic chemicals down away from the faces of experimenters. On the Space Station, creative solutions may be required to perform a similar function. The greatest personnel hazards are from eye contact, inhalation, and ingestion.

16. DECENTRALIZATION OF HAZARDOUS WASTE

Decentralization rather than centralized handling of waste again became a theme of the "Industry approach". Control the hazard as quickly as possible and isolate it from other locations in the system. This applies even to the laboratory module level. Industries' laboratories are isolated totally from the rest of the facilities. The Space station ECLSS integrates the module atmospheres for control of the total pressure, oxygen partial pressure, CO₂ removal, trace gas contaminant monitoring and control, and some humidity control. If an emergency occurs within a module, there is the capability to isolate it from the rest of the station configuration but this occurs after the fact. Normally, in the interest of safety and crew rescue, hatches to the experiment modules should remain open during experiment operations and only closed in the event of an emergency.

EXPERIMENT DESIGN

17. IS VACUUM VENTING ALLOWED ?

Many of the experiments in high temperature materials science require an external vent line for two reasons: (1) to rough pump a vacuum on the experiment and (2) to expell inert gases (e.g. He and Ar) which have been used during the experiment process. Although vacuum venting has been used on previous Spacelab flights, there was considerable disagreement regarding its allowance on Space Station. Arguments largely related to the degree of contamination to the external environment. Additionally, although the US users are actively debating this question, it appears that ESA will continue in the Spacelab mode. Therefore, the present station design calls for a US lab which will not allow users to vent inert gases overboard, therefore constraining or eliminating many experiments, while the Columbus will allow it. Resolution of this question must occur as soon as possible. Systems design can not proceed without a decision, and analyses will be required in any case.

18. THE NEED FOR AN EXPERIMENT DESIGN DATA BASE

As stated earlier, there is much confusion among new experiment/facility developers concerning levels of containment, hazards, fault tolerance, etc. There is an early need to establish a data base of criteria and acceptable designs which have previously flown. Many new furnace designers are again re-inventing the wheel and not benefitting from the data generated during Shuttle and Spacelab flights.

19. AVAILABLE CREW TIME FOR EXPERIMENTS

There is still considerable discussion regarding crew availability to perform experiments, experiment reconfiguration, and repair. While crew time may be a factor in equipment design, the science objectives shouldn't be compromised in order to achieve total autonomy. Whether or not an experiment requires extensive crew time depends somewhat on its discipline (e.g. life science experiments may require much crew time) and its objectives. Designers should try to optimize both automation and crew interaction. Where crew operation is required to achieve science objectives, then this should be articulated and coordinated early in the design process. In many cases, automation is less flexible, more costly, and more complicated than use of the crew. Automation lends itself to routine and repetitive tasks and should be used accordingly. Astronauts at NASA/JSC have established a Science Support Group to work with scientists and engineers early in the design process.

20. GLOVEBOX DESIGN AND USER REQUIREMENTS

The Glovebox briefings revealed the need for more user involvement to define user requirements. It wasn't clear whether the potential users of the glovebox (who must interface their experiments with it) were at the workshop. Users must spend more time with the designers and representatives of the astronaut office discussing experiment operation and requirements. Unless this occurs, equipment such as the

glovebox, the PMMS, and the general lab support equipment will not be properly developed. More meetings between real lab users and the hardware designers must occur.

INTERNAL CONTAMINATION DETECTION AND CONTROL

19. EXPLORE INSTRUMENTATION TECHNOLOGY MORE THOROUGHLY

Presentations on internal contamination and control showed exciting applications to space station problems. In particular, the government's military programs on chemical and biological warfare has produced instrumentation and removal devices that have significantly more capability than any of the current systems being investigated. NASA needs to explore these developments and determine whether they are first generation systems for the space station or second generation, evolutionary systems that we could place on the station within its 30 year life. The specific items are the MS/MS technology presented by Dr. Marsh and the reactive bed plasma system for contamination control presented by Mr. Joe Birmingham. The particulate detection technology presented by Mr. Robert Caldow appeared to have Space Station applications as well.

RECOMMENDATIONS

POLICY AND ORGANIZATION

1. Establish clear and uniform Safety Policies for all modules: JEM, Columbus and USL. Approaches to safety policy implementation should be similar to those used for ground based national laboratories (consult NRC guidelines).
2. Expedite development of the Space Station Safety Organization and utilize existing NASA safety organizations as required. (Flow chart the different center responsibilities)
3. Develop accident scenarios, such as for "in-cabin spills", and assign responsibility for detection and removal (both hardware and procedures development) to appropriate organizations.
4. Require all modules to develop *common* approaches to the distribution, handling, containment, and use of toxic and reactive materials. Safety dictated designs should immediately be transmitted to JEM and Columbus developers.
5. Improve communications across the board: NASA centers, International partners, contractors, users, industry, flight operations, safety organizations, etc
6. Schedule more user/designer/operator workshops to communicate safety related design requirements.

STATION SUBSYSTEM DESIGN

7. Utilize more ground based laboratory safety features.
8. Reevaluate the total number of ECLSS stations for trace gas monitoring.
9. Conduct a separate review of the PMMS in the following areas: waste storage systems, commonality with JEM and Columbus, 30 year flexibility, waste limitations as they relate to user requirements, introduction of wastes to the system, and quantity of water required for operations.
10. Evaluate potential locations and design requirements for a decontamination center in lieu of an "emergency shower".
11. Reevaluate isolation of the ECLSS avionics air loop from experiments.
12. Review ECLSS, FMS, and PMMS designs with respect to human factors: maintenance and repair, caution and warning, and emergency procedures.
13. Expedite the definition of Space Station SMAC levels.

14. Examine the benefits and limitations for decentralization of hazardous materials handling.
15. Determine if design verification for certain fluid handling systems is required aboard Space Shuttle flights prior to Space Station implementation.
16. Optimize air flows within the modules and the gloveboxes for safer operations.

EXPERIMENT DESIGN

17. Determine the status of potential contamination due to external venting of experiment waste gases by all module elements. This information must be acquired immediately so that design processes for the FMS and experiments can continue. (The External Environments Working Group may be performing this assessment)
18. Generate a Space Station User's manual and an experiment design data base which discusses design requirements as they relate to safety.
19. Re-examine crew operations of experiments both from a safety point of view and for optimizing scientific return. Optimize the automation/crew operation mix.
20. Reevaluate the glovebox design and user requirements (utilize previous flight experience with the ESA glovebox flown on STS-61A)

INTERNAL CONTAMINATION DETECTION AND CONTROL

21. Improve communications with both industry and the military for detection, removal, and control of toxic and reactive materials.

2. WELCOME

Edgar R. Pevey and Kenneth R. Taylor

Edgar R. Pevey*

Good morning ladies and gentlemen. On behalf of Teledyne Brown Engineering, NASA Headquarters, Marshall Space Flight Center, and the MMPF Study Team -- welcome to Huntsville, Alabama, the Huntsville Hilton, and, in particular, to our workshop "Space Station Toxic and Reactive Materials Handling". I am Ed Pevey, Manager, Engineering Studies, Advanced Programs Department, Space Programs Division at Teledyne Brown.

Prior to the start of the workshop, I wish to recognize some of our key players and those team members responsible for pulling together the participants in this workshop.

First, from Marshall Space Flight Center, our customer Mr. Ken Taylor, Chief, Materials Processing in Space Group; a member of Ken's group and the Contracting Officer's Representative for the MMPF Study - Mr. George McCanless. This workshop is being funded by Codes E, R, and S and to them we are grateful for this opportunity.

Next, from Teledyne Brown Engineering, our Vice President of Space Programs Division - Dr. Owen Garriott. The Manager of Advanced Programs - Mr. Anthony Sharpe. My workshop team: The workshop coordinator - Mr. Paul Galloway and administrative assistants Ms. Becky Dew and Ms. Teresa Strother.

We are indeed pleased to recognize and welcome several former astronauts/mission specialists Dr. Bill Pogue, a former Skylab astronaut, and Dr. Bonnie Dunbar, a mission specialist on the Spacelab D1 mission.

Next, I wish to recognize our Session and Panel Chairpersons.

Session 1 - Mr. Charles Baugher, NASA/MSFC

Session 2 - Ms. Judith Robey, NASA HQ Code S

Session 3 - Mr. Richard Tyson, NASA HQ Code R

Panel Chairperson - Dr. Bonnie Dunbar, NASA/JSC

Panel Members - Dr. Martin Coleman, NASA/JSC

Mr. Kenny Mitchell, NASA/MSFC.

*Manager, Microgravity Materials Processing Facility (MMPF) Project, Teledyne Brown Engineering

Again, to all of you -- both participants and attendees - a very warm Alabama welcome.

At this time, I present Mr. Ken Taylor for his opening comments.

Mr. Taylor has over 26 years of experience as a Project Engineer, systems engineer, and Program Manager. Mr. Taylor is chief, Materials Processing in Space Group within the Advanced Systems Office of the Program Development Directorate at NASA's George C. Marshall Space Flight Center in Huntsville, AL. The Materials Processing in Space Group is the focal point for planning and managing activities in the new field of materials processing in space.

Mr. Taylor is currently a member of the AIAA Technical Committee for Space Processing. He is a graduate of Mississippi State University with a degree in mechanical engineering.

Please welcome Mr. Ken Taylor.

Prior to our first speaker I have a few administrative announcements.

- The registration desk will be maintained just outside this room. There to assist you with telephone messages, etc. are Becky and Teresa.
- Dinner tickets are on sale - encourage you to invite your spouse.
- We have microphones in the audience - if you have a question please step to the microphone, state your name, and then ask your question or provide comments. If we run out of time for questions, feel free to question the speakers off-line or bring your question up during the panel discussions.
- Our daily schedules are tight - please observe the start time and be seated on time.

Now, I present Mr. Anthony Sharpe who will provide the outline of the Workshop Program.

Mr. Sharpe has over 25 years of combined aerospace and space experience as Manager and Project Manager of various systems engineering and Space Station definition studies. Prior to coming to Teledyne Brown Engineering he was with SPAR Aerospace Limited in Canada where he was a Manager in the Shuttle Remote Manipulator System Division. With Teledyne Brown Engineering, he is Manager of the Advanced Programs Department, Space Programs Division. He received his Bachelor of Science degree from the University of Leeds, England. Please welcome Mr. Tony Sharpe.

Kenneth R. Taylor*

From a payload point of view, the advent of Space Station offers us tremendous increases in the capability to operate in space.

- About an order of magnitude increase in power
- Over 5 times the time compared to 10 shuttle flights per year
- Significant increases in volume
- Perhaps an order of magnitude increase in mass of on-orbit payload equipment

In space just as on earth, the amount of R&D that can be done is to a large degree dependent upon the time available to do work, the power available, and the volume and mass of the equipment available. So, the Space Station offers us some great opportunities to expand R&D in space. Moreover, the cost of space R&D, which particularly important to commercial users, is directly affected by the volume of payload activity. The fixed cost of launch and operations can be diluted by increasing payload activity to yield lower cost per experiment run.

Therefore, we believe we need to prepare ourselves to capitalize upon these opportunities by ensuring that we know how to operate R&D payloads on the Space Station.

Essentially we intend to compare what is required with what is available in order to determine what we need to do to capitalize on Space Station to the fullest.

Fortunately, we have a lot of background available to us.

- There is our past experience on skylab and we have people that worked on board that vehicle and on the project.
- We have similar expertise from the Spacelab Module Project.
- We have designers, developers, and investigators on the key items of current and future payloads that will be adapted to or designed for the Space Station.
- We have expertise on the measurement, monitoring, and control of materials.
- And of course, we have key Space Station participants.

Our goal is an interchange between you that will begin to develop the design and operational guidelines that enable us to fully capitalize upon space to advance material science and technology, in particular, and space research and development in general. You

*Chief, Materials Processing in Space Group, NASA/MSFC

are the key to obtaining this goal. You have been invited not only for your expertise, but because of your dedication and can-do attitude to your work.

Therefore, we appreciate your help and hope that each of you benefit from this workshop as much as the workshop will benefit from you.

3. INTRODUCTION

OUTLINE OF WORKSHOP PROGRAM

Anthony Sharpe*

The advent of the Space Station will mark the beginning of a new and enormously exciting era of space experimentation and operations for NASA and this nation. For the first time since the Skylab days, people will live and work for extended periods of time in a permanent orbiting space facility. Their home will be the habitat module, in which they will eat, sleep, exercise and simply relax. Their workplace will be the laboratory modules, in which they will conduct a wide variety of materials processing and life science experiments, timeshared with many other operations (ranging from routine maintenance and repair, to monitoring and controlling external attached payloads). In the development of these modules the highest possible priority will be given to establishing provisions that will ensure crew comfort and safety at all times. This will be particularly challenging in the case of the laboratory modules, since certain activities within these modules (examples of which are: experiment setup, sample changeout, sample analysis, and experiment hardware cleanup) may require crew interactions with hazardous materials.

NASA Headquarters and the Marshall Space Flight Center recognize that the need to accommodate and handle the wide variety of materials anticipated within the laboratory modules gives rise to major crew safety issues that must be resolved early in the Space Station program. Appreciating that, when complex issues have to be addressed, many heads are better than one (especially if they belong to experts!), NASA Headquarters (Codes E, R and S) - under the auspices of the "Space Station Environmental Steering Group," have given Teledyne Brown Engineering the task of organizing this workshop with the theme: "Space Station Toxic and Reactive Materials Handling."

We would like to extend a very warm welcome to all of you who have accepted our invitation to attend this workshop. Our aim, of course, is to "pick your brains"; but we also hope that these three days at Huntsville Hilton will prove useful and rewarding to you in your own work.

The workshop consists of three one-day sessions, organized in a logical sequence, beginning with a consolidation of hazardous materials handling requirements for Space Station, in Session 1; continuing with a review of current Space Station concepts (both hardware and operational) for handling hazardous materials, in Session 2; and concluding

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with a review of existing and advanced systems for detecting and controlling chemical contaminants, in Session 3.

Specifically, in Session 1, we will review our past experience in handling hazardous materials in space, and will include presentations on previous Skylab and Spacelab missions. Our review of present activities will benefit from presentations on upcoming Spacelab missions and the current work being performed by the Soviets. The future requirements for materials processing on the Space Station will be reflected in presentations on the six Code EN experiment facilities. Also, a presentation on life science payload requirements will identify the unique requirements of the life science community.

In the first half of Session 2, we will have an overview of the Space Station, and those subsystems that are dedicated to the role of handling hazardous materials safely. Two major Space Station subsystems that will be discussed are the Environmental Control and Life Support Subsystem and the Fluid Management Subsystem. Also discussed in the Session 2 will be the capabilities and interfaces of the Process Materials Management Subsystem, which is the primary subsystem of the United States Laboratory charged with the task of handling and disposing of hazardous materials. In addition, the Space Station's logistics capabilities will be addressed.

The second half of Session 2 will come to grips with the subject of manned systems and crew safety, which is the primary purpose of the workshop. NASA should be commended for addressing the crew safety issue early in the Space Station program while modifications to the hardware and operational concepts can be incorporated with little cost and schedule impact.

Our third and final session will address internal contamination detection and contamination control. We will have presentations highlighting existing contamination control devices, such as gloveboxes, and we will examine advanced technology developments and new processes for their potential application to the Space Station program. Various technical approaches to chemical contamination detection will be discussed in this session. Rapid and reliable chemical contamination detection will be one of the greatest technical challenges of the Space Station program.

Many of the speakers in the third session are not involved in the Space Station program, but have extremely relevant knowledge and experience to share with us. We do appreciate their willingness to spend this time with us and we are grateful for their technical contributions to this workshop.

Following each of the three sessions, there will be panel discussions, in which the subjects brought out during the sessions will be discussed by the panel members. We hope for strong audience participation in these panel discussions.

This workshop is intended to address Space Station laboratory module internal contamination issues and to answer some key associated questions. It is quite likely, however, that we will raise as many new questions as we answer!

On Thursday, there will be a summary of the entire workshop, with an outline of the major findings, conclusions, recommendations, and remaining concerns that surfaced during the presentations and discussions of the previous two days. Again, we hope for lively discussions on the part of the attendees and participants of the workshop.

A banquet is planned for tonight. We will have the great pleasure of an after-dinner speech by a former Skylab and Shuttle Astronaut, Dr. Owen Garriott, who is now Vice President of the Space Programs Division of Teledyne Brown Engineering.

It is our sincere wish that the outcome of this workshop will, in terms of value, be greater than the sum of its parts, providing a much-enriched knowledge base from which we can all work.

I would like to extend my own very best wishes to all of you for an enjoyable and profitable time in Huntsville, where the sky is most definitely not the limit!

It is now my pleasure to introduce the Session 1 Chairman, Mr. Charles R. Baugher.

SESSION 1

SUMMARY AND KEY ISSUES IDENTIFICATION

by

Session 1 Chairman: Charles R. Baugher

NASA - MSFC

SESSION 1

SUMMARY

Session 1 consisted of an overview of the United State's past, present, and future requirements for handling hazardous materials in space. The presentations or past experience included America's first Space Station, or "Skylab", and two Spacelab missions (D-1 and SL-3). Present space activities that were highlighted in the workshop were the upcoming Spacelab J and Spacelab USML-1 missions. Also, an overview of the Soviet MPS activities in space was provided as a basis for comparison of the planned U.S. MPS activities for the Space Station Freedom. The future requirements for handling hazardous materials in space were covered in presentation on the six code EN or MSAD Space Station facilities which are the current MPS experiment facilities. In addition, the hazardous materials and operations associated with non-human life science payloads were detailed in an informative presentation by a representative of the life science community.

One former and one current astronaut, Dr. William Pogue and Dr. Bonnie Dunbar, participated in the workshop and made presentations concerning lessons learned on Skylab and Spacelab. The information provided by these astronauts has direct application to the Space Station program. For the reason, it is important to provide in detail the key issues discussed by these representatives of the astronaut community.

Former astronaut Dr. William Pogue, who flew on the last Skylab mission recounted several experiences from his flight and made several points. First, was his concern for the potential of off-gassing from materials. Skylab had over-heated and several hardware items released toxic fumes as a result. Skylab's air was changed out twice before the crew entered it to eliminate most of these gases. Second, was his concern with leakage. The Skylab cooling system used glycol, and this system developed a leak. Dr. Pogue pointed out that the Skylab cooling system was designed to be a leak-proof system. Inadequate equipment was provided for the cleanup and the leaking material spread so much that glycol was detected in the air filters. Metabolic waste and other materials were a frequent source of spills, (for example, sweat thrown from the exercising crew members). Inadequate procedures existed for clean-up. Future missions should provide for these activities. Even with the best designs, accidents will happen. Procedures and tools should be developed to accommodate these contingencies. Thirdly, Pogue was concerned with particulates and their collection and removal. Air filters became packed with contaminants which were very difficult to remove. The vacuum system provided for removing such material was inadequate. A good vacuum system on future missions is highly recommended. Filters should also be large and be placed in locations with easy access, so they can be readily

cleaned. Fourth, Skylab suffered from many false alarms. This can lead to desensitization of the crew. Any fire detection or leak detection system should be designed to reduce false alarms. Fifth, fire and leak detection systems should reveal location of problem and hand-held units should be provided for further assistance. Skylab did not have this capability and it took an unnecessarily long time to research false alarms. Plus, in a real emergency the sooner a location is known the better the potential for remedial action. Sixth, any future gas detection system should be capable of detecting all contaminants. Skylab had no leak detection system. Seventh, a tool was used on Skylab which had a numbering system associated with the mechanism. These numbers were glued on and eventually came off. Future labeling systems should not be prone to this problem. Eighth, some combustion tests have indicated that entrained air in a fire extinguishers exhaust may actually feed a fire. More research needs to be done in this area. Ninth, Skylab tests showed that porous materials burn readily in a low-g environment. Lastly, Pogue was concerned by reliance on containment. On Skylab a camera was opened and it was full of broken glass. This glass was supposed to be contained within the camera. The main point is don't depend upon containment. Procedures and tools should be developed to overcome accidental material release.

Dr. Bonnie Dunbar gave an informative presentation on the Spacelab D1 mission. Her presentation was primarily an overview of the mission. She pointed out that a large reason for the missions success was because of extensive preflight training. She also emphasized the importance of crew members having extensive knowledge of the experiments and materials they are expected to handle. One minor point brought out was that the air flow from Spacelab is into the Shuttle middeck and flight deck area. Therefore, debris from Spacelab tended to collect in those areas. It was later pointed out that this would not be a desirable air flow pattern in the case of a hazardous material. One would want the air flow to be away from the crew. In discussing material science experiments, Bonnie pointed out that many materials are toxic only at high temperatures. One sample failed in the gradient heating furnace on this mission. However, a retrieval procedure had been practiced on the ground, this was successfully used on-orbit. The sample that failed was a late mission add-on, which had its composition changed from the sample it replaced. However, the crew was not informed of this change and used an incorrect thermal profile. This anomaly points up the need for tight control between any changes that the experimenter makes to his facility or materials and the need for the crew to be completely familiar with those changes and their consequences. A major failure occurred on D-1, silicone oil leaked from a facility and the oil spread over the rack surfaces and contaminated

other adjacent Spacelab equipment. This incident occurred because silicone oil will thoroughly wet almost any surface it comes in contact with.

No procedures or tools had been provided for clean-up. Future missions have to consider these eventualities. Dunbar encouraged rack developers to provide their own unique tools for equipment repair and operation. Dunbar concluded by saying: 1) Safety is the key to a successful mission, 2) an international policy for safety and these experiments is required, 3) the full safety burden should be shared between SS systems and experiment facilities, and 4) reliable chemical contamination detection units are needed now. She also recommended a new NRC safety document. She also had one comment on automation. You can't automate what you don't know, the crew will be required to make modifications to hardware and procedures.

As the result of Dunbar's presentation several comments were made. One was that in considering triple containment one needed to consider each material on an individual basis. Some materials are safer than others. A discussion of fault tolerance as opposed to triple containment then arose. Another point raised was that the SS does not allow free venting, which the Spacelab does. What operational impacts will this have on the users? Dunbar mentioned here that the glovebox on D-1 worked well except that it had only one glove size, which was too large for her after it was stretched out. Dr. Dunbar recommended various glove sizes for the gloveboxes that will be flown on Space Station.

KEY ISSUES

1. There is a strong conflict between the payload desire to vent waste and the restrictions on external contamination. Sixty-six percent of the existing MPS payloads require venting. The venting requirements do not define a venting allocation for each Space Station Module. All sides appear to be unaware of the rationale on the part of others, and little information is being exchanged. This issue calls for coordination by Level II since it involves many Codes and Work packages.
2. Off-gassing of equipment must be considered a source of potential noxious material. Strict controls should be imposed to reduce or eliminate this hazard.
3. Adequate equipment for lab cleaning must be provided. Filters and other hardware to be cleaned must be easily accessible and must be designed with cleaning requirements in mind.
4. Little consideration was given to ground operations with these hazardous materials. Who is responsible for these areas and what plans have they made for these operations? More attention needs to be given to this area.
5. The potential for various levels of waste treatment exists: at the rack level, at the module level, and for the entire SS. The specifics of these levels of processing need

to be defined as soon as possible as they will impact user hardware design. Many of these designs will be entering Phase A/B development very soon.

6. It is critical that fire and leak detection systems be designed to locate a leak or fire source. General alarms are inadequate. Reduction of false alarms is desirable and hand-held portable units for alarm follow-up are also desired.
7. The current requirement concerning storage of potentially explosive materials is misleading as stated. Strict interpretation of the requirement would indicate that hydrogen gas would have to be stored outside the module.
8. More organized and direct communications are required between Space Station and User technical personnel. In many cases the laboratory users are among the most knowledgeable authorities on handling compounds associated with their experiments and their expertise should be directly focused in a visible fashion. In addition, lack of information to design teams tends to lead to "worst case" over design as engineers attempt to develop systems to accommodate vague generalities.