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INTERDEPENDENCE OF SCIENCE REQUIREMENTS AND SAFETY LIMITATIONS ON THE SPACE STATION

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One of the compelling reasons for using a facility such as the Space Station for scientific research is the ability to carry out experiments in an interactive mode. The increased time in space coupled with the increased availability of equipment and supplies enables scientists to perform experiments, to observe results, and quickly to repeat the experiments using the previous results as a basis to improve the parameters. In past space experiments this interaction between experimenter and experiment was often severely limited and often necessitated return flights at much later dates. Science conducted with years between experiments proceeds too slowly to be of benefit to either science or the economy. Crystal growth experiments provide a case in point. A sample of lead-tin-telluride semiconductor was flown in October 1985. One run was possible and no on-site analysis was available. The sample was analyzed only upon return to earth. The results although interesting raise questions that require further experimentation. No repeat has been possible and will not likely occur before several more years. In a second example the high school student proposing the growth of lead iodide in space finally had his experiment run on the recent Discovery (STS-26) flight, but he is now in medical school. This mode of operation was a fine beginning, but science in the western world will not progress very far if this continues as the only mode of experimentation. It is too slow and inefficiently utilizes time, equipment, and personnel. So, one of the benefits of experimentation on the space station will be the ability to carry out the experiment, to immediately analyze the result, to calculate improved experimental parameters, and to quickly repeat the experiment. In this improved mode of operation there are new safety considerations that must be addressed in the design stages of both the station and the experiments. I shall share with you some of the chemical and procedural requirements, and I shall discuss some of the earth-bound storage, dispensing, and disposal techniques that may assist in the development of analogous procedures for the space station.

Each scientific discipline has its own specific lists of requirements for on-board analyses in the space station. In the area of crystal growth the manifest of materials will make an industrial hygienist on earth tremble. The exciting crystals of military and industrial importance are not restricted to benign aqueous solutions of proteins and harmless simple electrolytes. High temperature superconductors have barium, yttrium, copper, and oxygen; but some also contain thallium and other toxic, heavy metals. Semiconductors contain mercury, cadmium, tellurium, gallium, arsenic, lead, tin, indium, and antimony. Further, these materials are grown not at ambient temperatures but at temperatures that are 900° C to 1400° C or higher. Furnace designs are being developed that safely allow crystals of even these materials to be grown in space. After the growth has been completed and cooled to room temperature, the samples must be analyzed. This involves non-destructive testing if the equipment is available on the space station. X-ray diffraction, ultrasonic evaluation, optical absorption, and electronic probes are examples of these analyses. Often, however, such methods do not enable scientists to ascertain the needed information. The crystals must be cut and polished. The cutting operation can involve the use of corrosive chemicals and dust-producing saws, and the polishing and etching procedures use solutions that are often highly hazardous. Such reagents as liquid bromine, hydrofluoric acid, and concentrated alkaline solutions are common. A more detailed list of reagents and procedures is given on the viewgraph handouts. Proper labeling, storage, handling, and disposal of reagents will be essential to the successful, safe use of space station for significant science.

The interdependence between the needs of science and the dictates of safety should serve as a spur to the development of new techniques that will allow safe operation on the space station. The science requirements can be clearly defined using current earth-based techniques and needs. The safety limitations will determine which of these techniques and chemicals can be used in the environment of the space station. For those techniques and chemicals for which safe procedures have not yet been developed, encouragement ought to be given to develop new procedures. As an example of such safer procedures that can be developed, consider the development of an electrochemical etching technique for lead tin telluride, which replaced the highly corrosive Norr etch. Also consider the development of a gel based procedure to deliver chemicals in space. The storage, dispensing, spill clean-up, and waste disposal procedures to be used on the space station need to be developed early in the design stages so that scientists can begin looking for acceptable alternative procedures and reagents that can be used on the space station.

A later design feature may also be beneficial. Perhaps not as an initial part of the space station, but certainly as part of future designs, consideration should be given to the use of small, limited mission, detachable experiment and analysis modules [EAM]. The more hazardous reagents and procedures for which safer alternatives cannot be found may still be performed in space. In the event of an accident, the modules can be sealed off from the rest of the station. They can be detached, retrieved, and returned to earth for clean-up. In this way a spill or accident on one such module will not endanger the station or interfere with other on-going experiments.

In designing equipment and procedures to be used on the space station, some of the techniques used in earth-based laboratories can be used as starting points. The problems faced by small, college laboratories are in many ways analogous to those to be encountered on the space station. In both facilities there is the need to store a variety of reagents safely. Often these are incompatible. The volumes of chemicals in both laboratory environments are small and the variety large. This poses problems slightly different from those presented by bulk chemicals, but some guidance is still available from the U.S. Coast Guard's list of incompatible substances and the DOT mandates. Shipping labels and container label information are also helpful. Finally the information available in the MSDS should not be ignored. Storage by hazard category is the general rule in laboratory stockrooms, and should be used on space station as well. Incompatible reagents in close proximity are intolerable on earth, and they are likely to be in space as well. Storage space is at a premium in both earth-based and space-based laboratories. Many questions need to be answered. How can provision be made for the storage of flammables? Do the same flammability figures apply in space? How many separate storage cabinets will be needed? Must their design be modified for the way in which flames propagate in space? Should they be vented, and if so what is to be done with the fumes? The procedures used on earth will be outlined in the viewgraph handouts.

In dispensing chemical reagents on earth, positive and negative air pressures need to be considered. Important as this principle of laboratory design is for earth-based laboratories, it may take on added importance in the space station, for this may be the major source of hazardous substances that move from one part of the station to another. In the event of a spill on earth, the procedure is to dyke with a neutralizing solid, and bag for disposal as illustrated in the viewgraph handouts. What analogous procedures will be developed for use in space? How many different neutralizing clean-up kits will be needed? How many will be needed and in what locations? If an error is made on earth, adequate ventilation can be obtained by opening a window and turning on a hood; the same simple solutions are not possible in space. Or are they? In disposing of reagents the problems faced by earth and space laboratories are likewise analogous. The toxicity and reactivity must be reduced, the volumes reduced, and procedures for the safe storage of a mixture of wastes developed. Chemists have been working on such storage and handling problems, and the recent environmental protection laws have spurred even further developments. A list of references for such procedures will be given in the viewgraph handouts. Finally, in earth-based laboratories accidents often occur in the most unsuspected places; and the same is likely in space. The drain traps can often be sources of trouble, since a variety of reagents are often mixed in them.

Although it is true that the college and space laboratory environments are similar in many respects, there are still some significant differences. Liquids will not pour in a preferred direction in space unless provision is made to force them to do so. They may not coat the samples or adequately mix. The absence of gravity driven convection will make mixing reagents and the removal of heats of reaction more difficult. This may allow for the unanticipated build-up of hazardous local concentrations of heat. The analogous problem faced in polymer synthesis will be reviewed.

Just as the problems faced in small laboratories on earth can provide guidance and insight to experimental procedures that can be adapted for use in space, the procedures and reagent handling systems developed for safe use on board space station, will be useful here on earth. One of the greatest future expenses to be faced by these small facilities is the ever increasing cost and difficulty of safely and legally disposing of spent and surplus chemicals. Techniques that work for space station have an immediate application right here, right now in schools, colleges, and small laboratories.
Further commercial possibilities of this spin off exist. Procedures developed for space station will likely not require continuous human intervention. The automatic and robotic procedures developed for space station will have application in improving the safety and productivity of industrial processes. Finally, as space station and its technology begin to be applied, further experimentation in the schools of this nation will be possible. This can only encourage the preparation of the scientifically literate population needed in the next century.

Safety and science requirements are interdependent spurring the development of new procedures and modified engineering designs. These developments will not merely be useful on space station, for they have far reaching applications on earth.

THE SCIENTIFIC UTILIZATION OF THE SPACE STATION DEPENDS UPON:

a. **Experimenter Interaction with Experiments**

b. **Rapid Repetition of Experiments**

c. **On-Station Analyses of Results**

SIMILARITIES OF ENVIRONMENTAL PROBLEMS BETWEEN COLLEGES AND THE SPACE STATION:

a. **Size** -- limited space which impinges on other functions

b. **Large Variety of Reactions Requiring Preparation** -- not specialized, must have flexibility.

c. **Large Variety of Reagents Needed** -- cannot wait for stores to be ordered and delivered

d. **Safe Reagent Storage** -- variety must be stored safely for long periods of time

e. **Waste Mitigation, Storage, and Disposal** -- a relatively new problem requiring new solutions

f. **Spill Control Preparation and Procedures** -- equip facility to handle all possible accidents

g. **Air Flow and Quality** -- regulate unexpected movement of liquid and gassous reagents

h. **Extensive Training of Supervisors** -- expect the unexpected.

AN EXAMPLE: REAGENTS AND EXPERIMENTS FOR CRYSTAL GROWTH --

a. **Solution Growth** -- water and/or non-aqueous fluid solvents for
   - proteins -- benign case
   - organic compounds -- flammable and/or toxic solvents and solutes

b. **Melt Growth** --

Temperatures:	ambient → 400°C, lead halides and model compounds
	400-1200°C, LTT, GaAs
	>1200°C, GaAs, ceramics
Procedures:	Czochralski
	Bridgman

c. **Chemical Vapor Decomposition** --
gaseous flow systems such as organometallic tin in gaseous hydrogen, silane in hydrogen, and gallium arsenide from trimethyl gallium and arsine

INSTRUMENTAL TECHNIQUES OFTEN REQUIRE REAGENT FLUIDS:

1. **HPLC -- requires solvents which are often organic**

2. **TLC -- requires solvents which are often organic mixtures**

3. **Electrophoresis -- requires solutions including organic ones**

4. **GC -- requires carrier gases. FID requires hydrogen**

5. **AA -- requires flames and nitrous oxide, acetylene, and oxygen or graphite furnaces. Both burners generate metal vapors**

6. **Optical Microscopy -- require sample preparation including cutting, polishing, and etching**

REAGENTS AND EXPERIMENTS FOR ON-SITE ANALYSES:

a. **Cut and Polish**

1. water
2. organic liquids
3. acids/bases, dilute to 18M H_2SO_4 and 50% KOH
4. special corrosives, e.g., HF, Br_2, and mixtures such as Norr etch

b. **Etch**

1. less concentrated than for cutting and polishing but still corrosive and/or toxic
2. many developed some specific for particular faces and dislocations

AIR AND FLUIDS MANAGEMENT:

a. **Storage**
by categories
guidance from USCG, chemical suppliers, MSDS, DOT shipping labels

b. **Dispensing**
microgravity creates the need for new solutions but similar to movement of reagents in vacuum lines.

c. **Mixing**
microgravity creates the need for new solutions but similar to polymer solutions and gels.

d. **Spent Reagent Management**
traditional methods -- burn, bury, hide, give away or otherwise forget
newer methods -- dilute, precipitate, distill, react, recycle
stabilize -- Hazardous Chemicals: Information and Disposal Guide by M.A. Armour, L.M. Browne, and G.L. Weir from the University of Alberta
safe storage for return
variety leads to unexpected reactions in drains or space station equivalent
possible on-station utilization/disposal will improve on the best methods developed in response to environmental pressures

e. **Spill Management**
traditional methods -- dyke, neutralize, store, disposal
newer methods for space station -- creative solutions may not eliminate the unexpected mixing of two innocuous reagents which are dangerous in combination. Remember the drains!

HOPE:

a. **New procedures can be developed, e.g.,**
   1. **electrochemical etches**
   2. **soda straw gels for dispensing reagents in space**
   4. **new organometallic reagents of III-V compounds**
   5. **blow-down tunnels versus recirculating reagents in CVD**

b. **Motivation is needed.**

c. **Some accommodation by station designers, i.e., design for the unexpected and prepare detachable modules for use with hazardous reagents. Use also as robotic center-of-mass experimental platform.**

d. **There is an interdependence between the safety limitations which should drive new modifications in the science experiments and the science requirements which should drive new designs for safety.**

AN ADDED BENEFIT:

As the college and small research laboratory provides useful terrestrial examples for the experimental problems anticipated to exist on the space station, so too do the solutions developed for the space station find immediate terrestrial applications.

In thinking for the space station one ought not to forget the commercial possibilities on earth now.

TYPICAL ETCHES:

GaAs	rinses 2-propanol or methanol	
	1:1:5	H_2O : H_2O_2 : H_2SO_4
	3:1:1	H_2SO_4 : H_2O_2 : H_2O
Si	10:1:1	H_2O : H_2O_2 : NH_3
	3:1:1	H_2O : H_2O_2 : HCl
	10:1	H_2O : HF
	42g/100g	CrO_3 in HF
	50g/100ml	CrO_3 in H_2O
InP	0.2-0.5%	Br_2 in methanol
SnTe	6:3:1	HOAc : HNO_3 : HF
PbSe	4:1:1	glycerol : HOAc : HNO_3
	10:10:1:½	H_2O : KOH : glycerol : H_2O_2
PbSnTe		Br_2, HBr, H_2O, glycerine
HgCdTe	spray etch using N_2 gas: Br_2 in methanol, alkaline glycerine with H_2O_2, HF and H_2O_2 in H_2O rotate sample at >6000 rpm	
GaP	1:3	HNO_3 : HCl (aqua regia)