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INTERNAL CONTAMINATION

IN THE

SPACE STATION

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INTRODUCTION

This paper discusses atmosphere trace contaminant control systems used in the past (Lunar Module and Skylab) and present (nuclear submarines and Shuttle), and makes recommendations for the future Space Station contaminant control system. The prevention and control methods used are judicious material selection, detection, and specific removal equipment. Sources and effects of contamination relating to crew and equipment are also discussed.

EFFECTS OF TRACE CONTAMINANTS

Trace contaminants can affect the crew, equipment and experiments.

Effects On The Crew

The compounds found in the trace contaminants can be divided into categories based on their major toxic effects. These categories, with examples are[1]:

1. Irritants: aldehydes, ketones and esters.

2. Asphyxiants: carbon monoxide, carbon dioxide*, fluorinated hydrocarbons* and methane*.

3. Central Nervous System Depressants: aliphatic hydrocarbons and alcohols.

4. Systemic Poisons: chlorinated hydrocarbons and aromatic hydrocarbons.

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*Displaces oxygen at high concentrations

An indication of the toxic risk from a given atmospheric contaminant is the ratio of its concentration (C) to its SMAC (Spacecraft Maximum Allowable Concentration) value. The relative toxic hazard index (RTHI) value of compound X would be expressed as $C_x/SMAC_x$. Any atmospheric contaminant that exceeds its SMAC value ($RTHI > 1$) would be considered to be at an unacceptably high level.

To some extent, multiple atmospheric contaminants that are in the same toxicological category exert an additive effect. The sum of all RTHI values in one toxicological category of an atmospheric sample can be referred to as the total relative toxic hazard index (TRTHI). It may be expressed mathematically as follows:

$$TRTHI = C_1/SMAC_1 + C_2/SMAC_2 + C_3/SMAC_3 + C_n/SMAC_n$$

C_x = concentration of chemical
$SMAC_x$ = SMAC value of chemical

The level of toxicity can be subjectively graduated from nuisance valve, to reduced productivity, to health hazard, to life threatening.

Contamination may affect the drinking water supply, food storage and preparation equipment and air circulation equipment.

An additional hazard of some contaminants is their property as fuel for propagation of fire and explosion. Examples are H_2, CO, and CH_4.

Effects on Equipment

Monomolecular layers on microchips can affect the conductivity of electrical paths and capacitance of elements. Surface degradation and adverse corrosion can occur as well as clogging of microporous membranes, filters and operations. Optical surfaces are particularly vulnerable.

Effects on Experiments

Cross contamination can occur in biological experiments which can affect growth and fatality rates, thereby coloring conclusions referring to cause and effect. Non-biological experiments can also be influenced by contamination. Crystal growth, plating, flow reduction, and assembly can be affected.

SOURCES OF CONTAMINATION

Contaminants have been found to be generated by the crew vehicle equipment, experiments, operations, food and human waste disposal, cleaning fluids, and repairs.

Crew

Principal sources of contaminants from man are expired air, urine, feces, flatus, perspiration, vomitus and saliva (sneezing). Major contaminants generated by metabolic processes of the crew are: CO_2, NH_3, CO, H_2S, H_2, CH_4, organic acids and mercaptans. In addition, bacteria, virus, fungus, skin particles and hair and nail clippings will occur.[(2),(3)]

Equipment

Compounds generated by equipment generally have relatively high vapor pressure and are outgassed from solid materials and lubricants. Although NASA has done an outstanding job eliminating most of these contaminants in NASA owned equipment, experimenters and developers of manufacturing processes may not be able to conform to the guidelines presented in NHB 8060.1B,"Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion," September 1981.[(4)]

Experiments and Crew Activities

Experiments can release inorganic, organic, viral and bacteriological contaminants.

Contaminants will probably be released during food preparation, food and human waste disposal, and crew cleansing.

Accidents, Fire, Explosion, and Spillage

In addition to contaminants present during normal operations, one must consider the toxic atmospheres resulting from such upset conditions as fire or equipment failure, as well as the products of thermal decomposition due to overheating of electrical and hydraulic equipment. Carbon monoxide and aldehydes are frequent breakdown products in equipment fires. Thermal degradation of plastics will yield monomers and large chain fragments such as methyl alcohol, hydrochloric and hydrofluoric acids, and hydrogen cyanide.[5]

Accidents may occur during servicing of satellites, leading to an EVA astronaut's exposure to rocket fuels and oxidizers. These contaminants may then be brought into the station on EMU clothing or tools.

PAST CONTAMINANT CONTROL

Lunar Module

The lunar module contaminant control system consisted of particulate filters and activated carbon, for odor control, both packaged in the LiOH cartridges used to control CO_2. The pressure suits worn by the crew also aided contaminant control.

Langley (MDAC) 90-Day Manned Test - 1970

Objectives of the 90-day operational manned test involved the evaluation of an advanced regenerative life support system similar to that of an orbiting scientific laboratory under closed-door conditions. These objectives included determination of long-term operating characteristics and power requirements of individual subsystems and the total system; measurement of mass and thermal balances; determination of the ability of the test crew to operate, maintain, and repair onboard equipment; measurement of chemical and microbial equilibrium of the closed life support system; assessment of the effect of confinement on the psychological and physiological characteristics of the test crew; and collection of data to assist in determining the role of man in performing in-flight experiments.[6]

This test operated with no materials passed into or out of the test chamber. The composition of the atmosphere during the manned operation was determined on a continuous basis and by individual samples taken at frequent intervals. Analysis was done by chromatograph on direct samples. Concentrated samples were also obtained by freeze-out techniques and sent through the gas chromatograph to determine the presence of organic compounds. Inorganic compounds were measured by wet chemical analysis on samples taken daily.[7]

Contaminants were controlled during the 90-day test by employing a 1.5 cfm toxin burner (integrated with a Sabatier reactor for thermal efficiency), along with particulate filters, solid amine CO_2 control, molecular sieve CO_2 control and a condensing heat exchanger. The cabin air was almost free of contaminants during the unmanned and manned periods preceding the 90-day test. During the 90-day test there were no inorganic compounds noted. There were no NO_x compounds until NH_3 reached 0.5 ppm. The NO_x disappeared when the toxin burner was shut down, indicating NO_x was formed from NH_3 in the toxin burner.

Analysis of the CO_2 just upstream of the Sabatier reactor showed the presence of Freon 113. The average detected concentration of Freon 113 varied from 9.0 ppm, when the solid amine unit was operating, to 33.8 ppm, when the molecular sieve unit was operating. Acetone and ethyl alcohol were also detected in the CO_2 at low concentrations. These results indicate that the CO_2 scrubbers were able to remove some of the trace contaminants.

Skylab

The Skylab environmental control system had considerable capability to scrub the cabin air of generated contaminants. Principal elements of the system were the charcoal canisters in the molecular sieve unit and waste management systems, the condensing heat exchangers, and the Linde 13X and 5A molecular sieve material.

The molecular sieve and charcoal canisters performed their design function of removing odors, as well as removing contaminants. The only means available to evaluate the performance of the odor removal system was via crew comments, but all three crews indicated that the system performed very well.

Ground tests in which air laden with various concentrations of trace contaminants was passed through special test bed molecular sieves, qual unit molecular sieves and a Gemini condensing heat exchanger indicated that molecular sieve material had 100% removal efficiency for all contaminants tested with the exception of H_2 and CO as shown in Table 1. No removal capability was noted for these two gases. The condensing heat exchanger had some capability for contaminant removal, especially for Coolanol 15.

TABLE 1

SKYLAB CONDENSING HEAT EXCHANGER AND

MOLE-SIEVE CONTAMINANT REMOVAL EFFICIENCY

Contaminant	Test Inlet Concentration, ppm	Removal Efficiency, Percent	
		CHX	Mole-Sieve
1. Hydrogen	900	(1)	0
2. Ammonia	60	(1)	100
3. Methyl Chloride	20	(1)	100
4. Freon 12	500	(1)	100
5. Benzene	5	8.7	100
6. Freon 113	500	(1)	100
7. Xylene	50	(1)	100
8. Toluene	50	(1)	100
9 Acetone	500	(1)	100
10. Isopropyl Alcohol	100	(1)	100
11. Acetaldehyde	50	2.6	100
12. Methyl Isobutyl Ketone	10	33	100
13. Dichloromethane	25	(1)	100
14. Carbon Monoxide	75	(1)	0
15. Methyl Chloroform	90	15.2	100
16. Methyl Ethyl Ketone	100	1.1	100
17. Coolanol 15	50	89	100

(1) Not tested.

PRESENT CONTAMINANT CONTROL

Shuttle and Spacelab

The Shuttle and Spacelab trace contaminant control systems each include activated LiOH canisters, a condensing heat exchanger and a carbon monoxide oxidizer.

Four atmospheric samples were collected at approximately 12-hour intervals in the orbiter crew cabin during the 56-hour STS-1 mission on April 12-14, 1981.[8] Post-mission gas chromatographic/mass spectrometer analysis showed 57 different chemical contaminants; 38 were structurally identified. The total quantity of gases in each toxicological category was below the SMAC value of any one of its constituents. The only categories of gases that approached the SMAC value for any one gas in their category were the systemic poisons and asphyxiants. However, in both cases, these values were below the concentration of gases with the lowest SMAC value. The catalytic oxidizer for CO control was not present on the STS-1 mission.

Submarines

In view of the convergence of the requirements for spacecraft and submarine life support systems a study, jointly funded by the Navy NAVSEC and NASA was prepared by Hamilton Standard in 1974[9].

In this study, for submarines, activated carbon was selected to control trace contaminants, as well as odors, hydrocarbons and "Freon" spills. On present submarines, aerosols are controlled with strategically placed filters and electrostatic precipitators. A Hopcalite catalyst operated at high temperature is now used to control CH_4, H_2 and CO.

Detection of trace contaminants on submarines is accomplished by a Perkin-Elmer Central Atmosphere Monitoring System (CAMS) which uses a mass spectrometer to monitor all trace contaminants except CO. An infrared analyzer monitors CO.

SPACE STATION

Contaminants expected in the Space Station can be divided into the following main categories:

- Those present during normal operation
  - Contaminants generated by the crew and equipment
  - Contaminants generated by experiments and manufacturing
- Contaminants generated by fire and explosion

As demonstrated by previous Skylab flights and STS-1, the combination of prevention (selection of materials), proper waste handling, and minimal removal equipment resulted in odor-free flight on Skylab and no contaminant reaching its SMAC value on STS-1.

However, it is expected that the desire to open the station to a broad user community will necessitate some relaxation of NHB 8060.1B. Therefore, higher levels of particulate and gaseous contaminants will be generated, requiring control equipment which is more sophisticated and has larger throughput than that used on Skylab and Shuttle.

In addition, the cabin volume and crew size will increase in proportion to the space station size while cabin air leakage can be expected to decline, particularly for non or low EVA activity missions.

As a result, the need to control low molecular weight contaminants, particularly CH_4, will require a high temperature (600°F) catalyst.

The high temperature catalytic oxidizer developed by Hamilton Standard is relatively insensitive to the normal humidity levels found in the environment. Additional base sorbent beds such as $LiCO_3$ should be placed upstream of the catalyst bed to protect it from acid gases such as SO_2, H_2S and HCl. A base sorbent bed should be placed downstream of the high temperature catalyst to stop acid gases which may be produced in that catalyst bed, such as HCl and HF.

As noted earlier, the condensing heat exchanger can be used to control some of the trace contaminants, such as ammonia, methyl isobutyl ketone, methyl chloroform and benzene which have been demonstrated in laboratory tests to be removed in the condensate water. This water must then be filtered to remove these contaminants if it is to be reused.

Particulates and aerosols can be controlled using absolute filters placed upstream of the fan and a condensing heat exchanger to remove particles greater than 0.3 microns including bacteria. The absolute filter prevents growth in the activated carbon and condensing heat exchanger. Debris traps should be placed upstream of the absolute filters to stop coarse particles (wet and dry) which make up the bulk of the particulate matter and may quickly clog the absolute filter.

Post-Fire Atmosphere Cleanup

In the event of a fire within the space station, the routine procedures for controlling and extinguishing the blaze should include shutting down the environmental control equipment in or serving the affected section. This action helps to lower the oxygen concentration in the area of the fire and restricts the distribution of the combustion products in the atmosphere to a local area around the fire site.

Once the fire is extinguished, the local atmosphere must be cleaned to remove suspended particulate materials and objectionable or toxic gases generated by the combustion before the ECLSS is returned to duty in order to prevent spreading the fire-generated contaminants to other parts of the station. Portable oxygen systems or other self-contained breathing apparatus should be included in the on-board emergency equipment.

One method of cleaning the fire-contaminated atmosphere would be to dump it by depressurizing the affected section. Depressurization involves added risk such as the bends if the crew had no other area in which to seek protection. In addition, depressurization of a large section of the space station will require the replacement of the N_2 and O_2 required. For example, a 5000 ft^3 section will contain 300 lbs of N_2 at standard conditions. In addition, there is a possibility of contaminating experiments or sensors outside the pressurized volume.

A portable post-fire air purification unit proposed by Hamilton Standard for use in U.S. Navy ships can provide the required cleanup capability without any interface with the ECLSS. The unit is entirely self-contained and requires only a source of electric power to operate its fan. It can reduce the level of carbon monoxide in a 5000 cubic foot enclosed volume from a fatal one-hour exposure level of 5000 parts per million to a safe one-hour inhalation level of less than 500 parts per million in about 20 minutes.

To clean up a contaminated compartment, the unit need only be allowed to run unattended within the closed volume until contaminant levels are sufficiently reduced as indicated by the ECLSS Monitor and Control sensors in the compartment or until visual and olfactory observations indicate the removal of smoke and odors.

SUMMARY

Skylab and Shuttle results have indicated that the combination of materials selection, onboard removal devices, and preflight offgassing tests can be an effective means of controlling spacecraft contaminant levels.

The following are recommendations for atmospheric contamination control on Space Station:

1. The maximum allowable levels of contaminants should be established by NASA.

2. An effective materials screening program should be carried out to eliminate materials with offgassing characteristics above established criteria; i.e., NASA should produce a list of acceptable materials.

3. Contaminants should be selectively monitored using a CAMS or similar unit.

4. A simple, standard procedure should be developed to test the flammability and outgassing of flight payloads and experiments. Standard cabinets should be considered, especially designs which accommodate special sorbent beds and interface with the catalytic oxidizer so that unique contaminants can be efficiently controlled.

Table 2 defines the elements of a contaminant control system envisioned for a Space Station. Additional equipment or designed-in, controlled cabin leakage may later be required.

TABLE 2

TYPICAL SS CONTAMINANT CONTROL SYSTEM

ITEM	TO CONTROL
Absolute Filters	Particulates, Bacteria and Aerosols
Condensing Heat Exchanger	Humidity Control (Moisture) and Water Soluble Compounds
CO_2 Removal Hardware	Carbon Dioxide Level
Activated Charcoal (Treated and Untreated)	High Molecular Weight Hydrocarbons and Ammonia
High Temperature Catalytic Oxidizer with Pre- and Post-Filters	Cabin Monoxide, Hydrogen and Low Molecular Weight Hydrocarbons; acid gases and products of oxidation

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INTERNAL CONTAMINATION: SPACE STATION LIFE SUPPORT ALTERNATIVES

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CONTAMINATION CONTROL ALTERNATIVES

1. Business as usual (preventative)
   - NHB 1700.7A (safety policy)
   - NHB 8060.1B (flammability, odor, offgassing)
2. Relax prevention guidelines
3. Revise prevention approach to soften burden on users; increase on-board control

THREE QUESTIONS FOR CONTAMINANT CONTROL

1. What is the contaminant?

2. What is its allowable level?

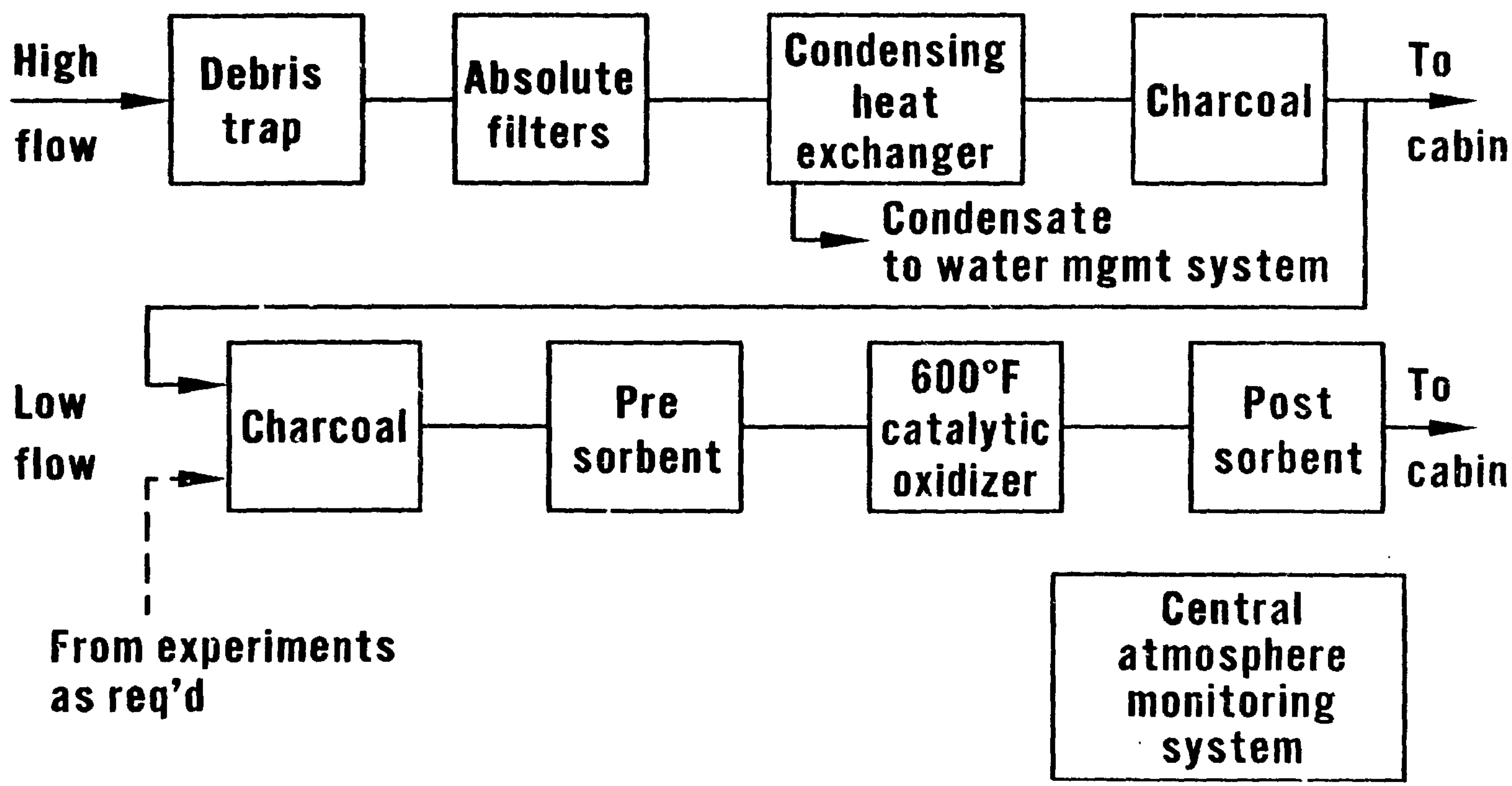
3. What is its production rate?

Having answers to these questions is key to controlling the contaminant.

CONTAMINATION AND HUMAN PRODUCTIVITY

- Effects on the crew
  - Categories/levels
- Sources of contaminants
  - Crew, equipment, experiments, accidents
- Non-venting regenerative life support for Space Station

TYPICAL TRACE CONTAMINANT CONTROL SYSTEM



SOME FLAMMABILITY/CONTAMINANT SCREENING IS MANDATORY

Without screening, Space Station payloads/experiments need:

- Isolated, fireproof module(s)
- Independent ECLS system(s)
- Over-designed contaminant control scheme with conservatively frequent filter/sorbent changes

The burden on station designers and the risk to the crew are inappropriate. Some screening is mandatory.

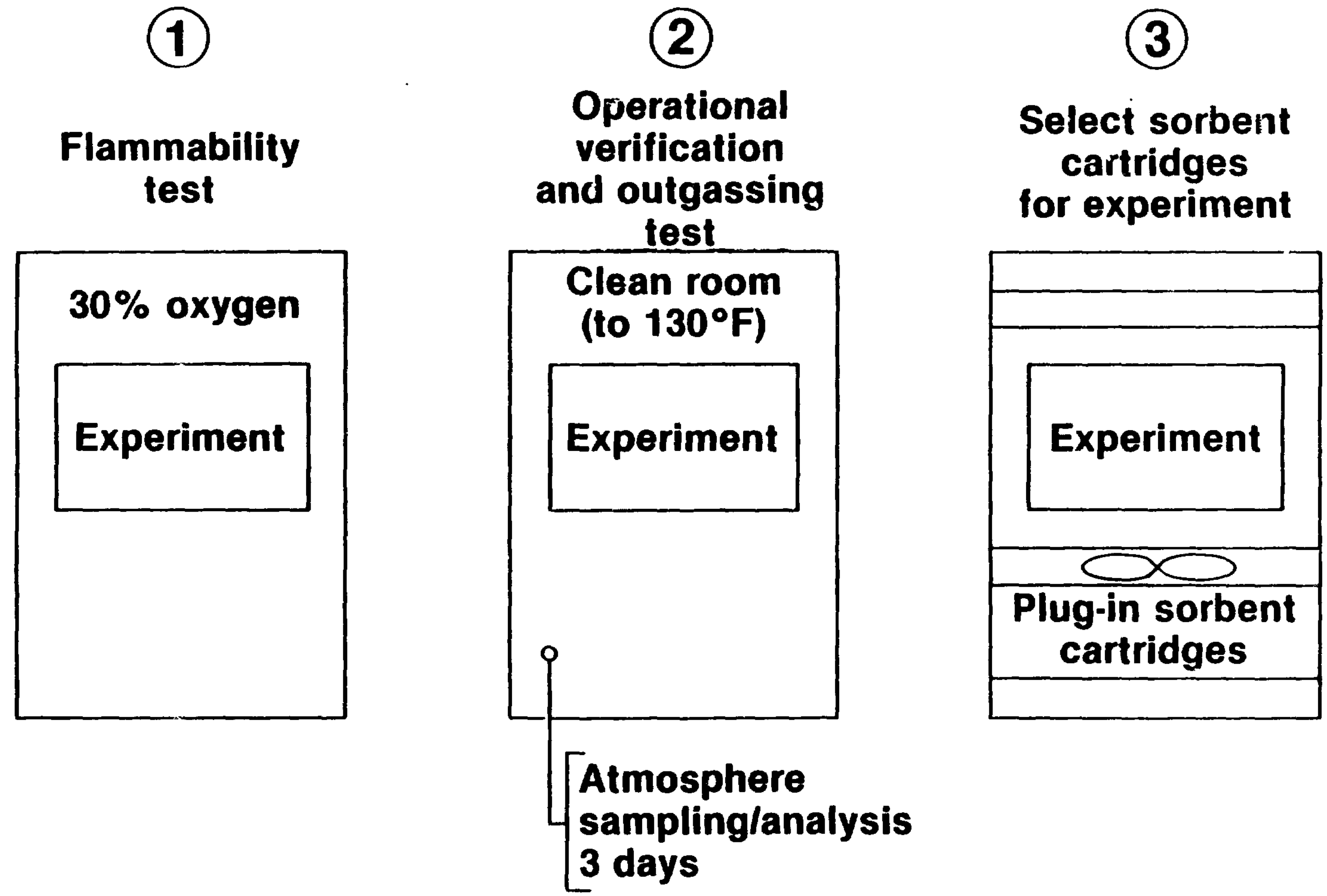
CUSTOMER - FRIENDLY CONTAMINATION CONTROL

1. NASA publish a list of approved materials

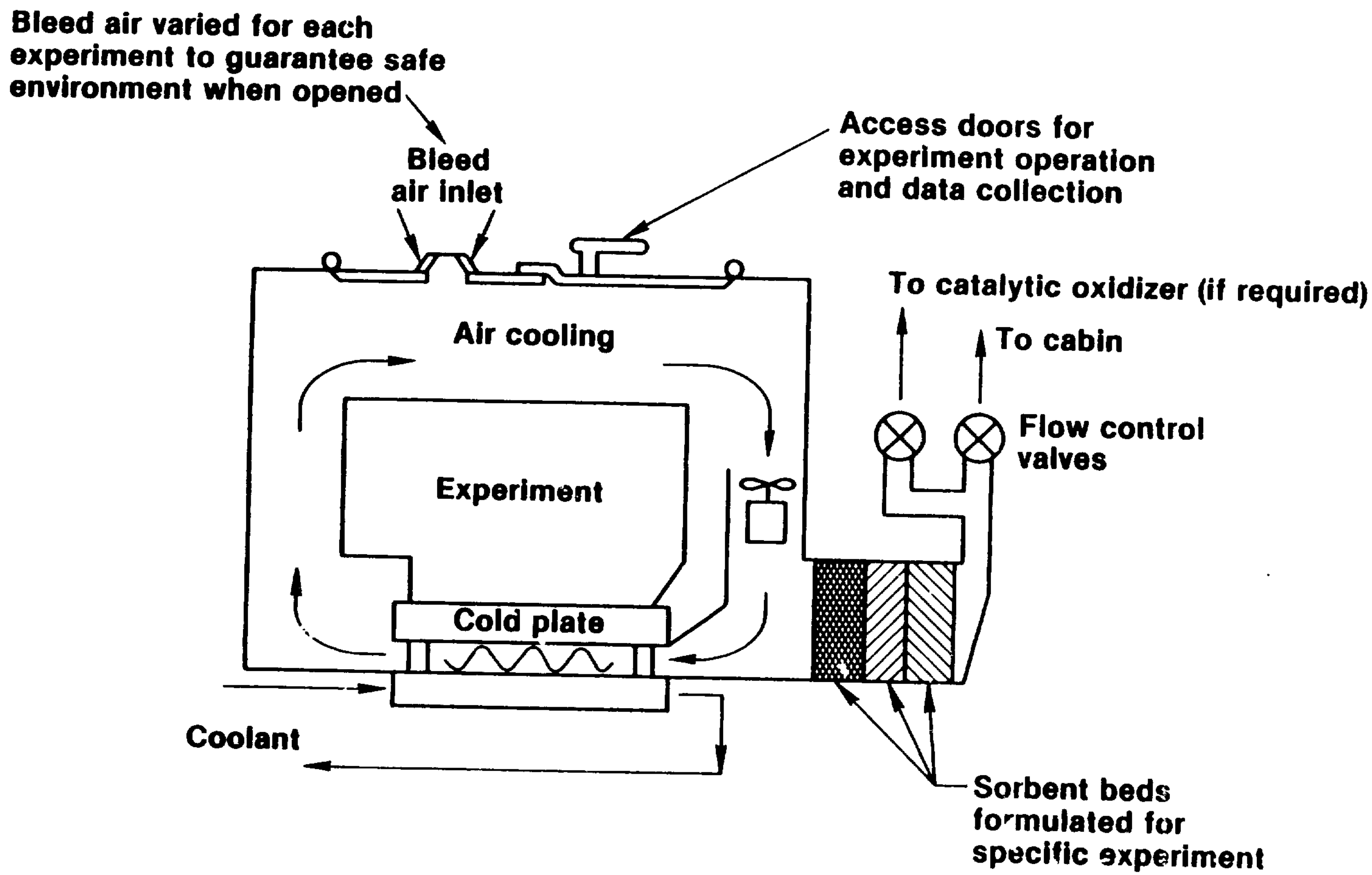
2. NASA publish a list of prohibited materials

3. NASA establish a "customer service" center with assigned payload "sponsors" to soften burden on users

USER'S EXPERIMENT/PAYLOAD CHECKOUT & SCREENING AT NASA FACILITIES



STANDARD CABINET FOR EXPERIMENTS SUSCEPTIBLE TO OFFGASSING



SMOKE/TOXIC GAS AIR PURIFICATION UNIT