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CONTAMINATION CONTROL CONCEPTS FOR SPACE STATION CUSTOMER SERVICING

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ABSTRACT

The customer servicing operations envisioned for Space Station, which include instrument repair, orbital replacement unit (ORU) changeout, and fluid replenishment for free flying and attached payloads, are expected to create requirements for a unique contamination control subsystem for the customer servicing facility (CSF). Both the core Space Station (SS) and CSF users present unique requirements/sensitivities, not all of which are currently defined with common criteria. Preliminary results from an assessment of the effects of the CSF-induced contamination environment are reported. Strategies for a comprehensive contamination control approach and a description of specific hardware devices and their applicability are discussed.

INTRODUCTION AND SUMMARY

The servicing operation is baselined to include capabilities for repair, replacement, replenishment, and refurbishment of potential users and/or user hardware. These users can be either free flying (FF) or station-attached payloads, and as a group, will present various degrees of sensitivity to contamination. For example, observatories such as the Hubble Space Telescope (HST), the Space Infrared Telescope Facility (SIRTF), and the Advanced X-Ray Astrophysics Facility (AXAF) are generally classified as extremely sensitive to molecular and/or particulate contaminants whereas other users such as the Gamma Ray Observatory (GRO) are considered to be less sensitive.

Due to the multipurpose function of the CSF, many sources of contamination can be introduced into the servicing area. Leaks from fluid replenishment subsystem components, extravehicular activities (EVA), outgassing from CSF materials of construction, and particulate generation and shedding from mechanisms and surfaces subjected to impacts or loads, can directly influence the contamination environment within the CSF. In addition, sources originating from the exterior of the CSF -- STS PRCS and VRCS bipropellant exhaust products, pressurized module waste product dumping and outgassing, atomic oxygen, and micrometeoroids -- can also compromise the cleanliness and affect the mechanical/thermal/optical properties of critical user payload surfaces.

In order to predict the degree of control needed to meet user requirements, an investigation was undertaken whereby major sources of contamination were identified, and their generation, transport, deposition, and ultimate effects characterized based on preliminary design information. EVA/EMU (Extravehicular Mobility Unit) water emissions, structural support member outgassing, and nominal liquid propellant leaks resulted in unacceptable levels of molecular contaminant film accretion and CSF ambient pressures for a tightly sealed enclosure with no contaminant collection or control. A neutral particulate analysis, which considered the dislodgement of particles from CSF interior surfaces as a result of a sudden impact force, resulted in the emission of relatively large particles ($\geq$50 microns) but low overall obscuration of user payload surfaces. A study addressing particle charging effects indicated a small degree of charging within the CSF and a significant reduction in particle migration/collection time if electrostatic particle collection methods could be employed.

Because of these preliminary modeling results, a contamination control subsytem concept was created to provide a means for maintaining the CSF within core SS and user specifications. The conceptual design consisted of candidate hardware components divided into four groups according to their function: (1) measurement/monitoring/alarm, (2) collection and control, (3) treatment/storage/disposal, and (4) cleaning and refurbishment. Actual sizing of the components was not performed at this time; however, qualitative trades were made for each class of hardware components, comparing factors such as collection or measurement efficiency, power/facilities requirements, reliability, and technology development requirements.

BACKGROUND INFORMATION

CONFIGURATION

The generic conceptual design of the CSF is illustrated in figure 1. This representation shows the basic rectangular box configuration of the servicing bay enclosure (SBE) attached to the station keel and supported by additional structural members. The dimensions of the enclosure are nominally 10.7 m (35 ft) square (in width and depth) and 27.4 m (90 ft) long. Figure 2 shows a retracted view of the facility revealing much of the servicing specific hardware and mechanisms currently baselined. The servicing mission must provide for manipulation and accommodation of both large and small users, housing of support equipment for (1) EVA (work stations, tools, etc), (2) thermal control subsystem hardware, (3) fluids handling subsystem equipment, (4) communications, data handling, and power distribution components, and (5) any contamination control devices deemed necessary for the resident user. The present baseline is that the CSF volume will remain unpressurized.

In relation to the core SS (dual keel configuration), the CSF is located in the +z half attached to one of the dual keels with its "top" located near the upper boom and, when extended (or "closed"), stretches some 27.4 m (90 ft) in the -z direction. This position is illustrated in figure 3. Placement of the CSF is important in that other SS elements -- habitable modules, subsystem components (thermal, structural, power, attitude and control, etc.), STS docking port, and Orbital Maneuvering Vehicle (OMV) docking and/or storage locations -- as well as direct line-of-sight to the RAM direction (atomic oxygen flux) and micrometeoroids can all have significant impact on the contamination environment within the CSF volume.

THERMAL AND ORBITAL ENVIRONMENTAL FACTORS

The proposed SS low earth orbit (LEO) will be at 28.5° inclination at an altitude of 460 km. Initial deployment and operating capability is expected to occur in the early to mid-1990s. Atomic oxygen (AO), ultraviolet (UV) and ionizing radiation, micrometeoroid impacts, and core SS surface charging can affect the behavior of any contamination sources present. Table I summarizes expected values for relevant environmental parameters (ref. 1). Materials compatibility and long-term stability should be considered as major issues for the maintenance of a suitable CSF environment.

Outer surfaces of the CSF are expected to vary in a cyclic manner between 200 K (-100° F) and 339 K ($+150^{\circ}$ F). Depending on its thermal mass, each component within the CSF will experience temperature fluctuations within this range. At least two sides of the SBE will attain the temperature extremes for a given cycle. The CSF thermal control system, consisting of an active thermal loop, cold plates, radiators, heaters, and the enclosure itself, will be operational to ensure that user thermal constraints are met and maintained.

SERVICING SCENARIOS AND TIMELINING

A mission list, which is shown in table II, commits the occupancy of the CSF for a range of 38 to 90 days per year; an option to close the facility during STS docking and departure would add an additional 8 days per year. EVA manpower requirements for servicing operations have been estimated at approximately 200 man-hours per year.

Specific mission scenarios and time-sequencing have been developed for certain initial operating capability (IOC) missions, but will vary according to the degree and type of servicing needed. However, common or generic operations have been identified, namely, OMV and remote manipulator system (RMS) type maneuvering and manipulation, followed by SBE extension ("closing of the CSF") and a host of probable servicing operations including mechanical/electrical interfacing, ORU replacement, EVA assisted refurbishment of damaged equipment, testing, verification, and checkout procedures, and final demating of the user payload. Elapsed time for servicing can range from 5 to 28 days or more; HST and GRO have been tentatively scheduled for 14 days each.

DEFINITION OF REQUIREMENTS

In lieu of common contamination control criteria not presently defined for all Space Station elements, a combination of space-measurable and earth-based requirements have been circulated within the program customer and contractor community. A major goal of the contamination control effort appears to be the standardization of molecular, particulate, and other pertinent environmental parameter requirements to facilitate interfacing between station elements. Relevant to customer servicing are (1) user payload requirements and sensitivities, and (2) core Space Station requirements.

USER REQUIREMENTS AND SENSITIVITIES

Requirements of this type have been seen to take on various forms -- contamination deposition rates, thicknesses, surface obscuration, "airborne" particulate servicing environment per FED-STD-209B, and surface cleanliness levels per MIL-STD-1246A. Functional performance requirements based on end-of-life goals have also been encountered. The heterogeneity of user sensitivities and omission of contamination budgets for servicing operations create additional confusion to the task of defining maximum acceptable limits as a result of servicing. A review of the various requirements summarized in table III indicates that extremely low levels of contaminaton can result in unacceptable degradation to the critical systems. A total accumulation of 20 angstroms of molecular contamination was allocated for HST optical surfaces (ref. 2), very little to none of which was budgeted for on-orbit operations such as servicing at the CSF. In general, particulate levels are not well defined. Particle concentrations can however, be expressed equivalently by FED-STD-209B guidelines taking into account that smaller particles (5 microns or less) will not settle by gravitational forces.

Maximum pressure requirements have been included to prevent failure of high voltage electronics as a result of exceeding critical pressures (e.g., exceeding the "Paschen pressure" for traveling wave tube assemblies (TWTAs) can result in arcing and subsequent system failure).

CORE SPACE STATION REQUIREMENTS

A preliminary set of core SS requirements has been circulated among program contributors. The set included criteria for (1) materials selection, (2) initial station hardware surface cleanliness, (3) background spectral irradiance, (4) molecular column density (MCD), (5) particulate background, and (6) molecular deposition accretion rates. External (unpressurized) and internal (pressurized) servicing requirements were outlined as well as provisions for monitoring and verification.

CONTAMINATION ENVIRONMENT MODELING AND ANALYSIS

In an attempt to provide a theoretical basis substantiating the need for a comprehensive conceptual design for contamination control, a preliminary analysis was performed predicting the contamination environment associated with the CSF interior and its potential effects on user payloads. A flow chart representation of the analysis, as seen in figure 4, indicates the basic data input and output information associated with the task. The results of the modeling effort, although preliminary, were beneficial in defining meaningful requirements in addition to providing baseline rationale for creating a distinct subsystem for contamination control.

CASE STUDY DESCRIPTION

The analysis focused on the servicing of an observatory class vehicle (HST) contained within the enclosed CSF. Simplifying assumptions were made to impart conservativeness and thereby create a "worst-case" scenario. Figure 5 illustrates HST secured in the CSF with the SBE in the retracted position. When closed, the SBE was assumed to prevent infiltration of contamination from the exterior; conversely, all internally generated contamination was not allowed to escape by "venting or leaking."

CONTAMINATION SOURCE IDENTIFICATION

Major sources of molecular contamination were identified and incorporated into the model based upon quantity, generation potential, relative effects, and availability of reliable data. Both permanent and intermittent/periodic sources were considered.

Particulate sources generated within the CSF were thought to be the result of several phenomena. Dislodgement and redistribution of existing surface particulate contamination, sloughing, flaking, or friction generated wear, and even impact-induced particle generation from both CSF materials of construction and EVA/EMU sources, were considered potential particulate cleanliness concerns. As experimental data on particle generation characteristics were found to be extremely limited, mechanisms based on theory were developed and generation data computed and input into the model.

A list of all sources considered, classified as either molecular or particulate, is shown in table IV. The current space suit and EMU are prone to particle generation from the outer layers of the thermal micrometeroid garment (TMG) and emit water and carbon dioxide continuously during EVA. Generation potential was defined in terms of outgassing rate test data* and customer/contractor supplied EMU emission rates.

DESCRIPTION OF MODEL

The molecular transport model employed was based on a simplified conservation of mass/kinetic theory of gases approach. The results were compared and verified (with very good agreement) by results obtained from a time-dependent, three-dimensional direct-simulation Monte Carlo solution. Generation and deposition rates were both considered as strong functions of surface temperature (ref. 3). Deposition thicknesses for both user payload interior and exterior surfaces were computed as were partial pressures resulting from each source.

An attempt to characterize the particulate contamination environment included (1) a charging effects analysis, and (2) a neutral particle dislodgement/ redistribution analysis. The charging effects investigation was undertaken to determine whether surface charge would play a significant role in particle

*JSC and TRW outgassing data.

adhesion and transport. The charged particle current densities existing at the proposed SS orbit altitude (460 km) and magneto-induced potential across the entire facility were analyzed and the influence of charging on neutral particles was estimated. Data supporting the feasibility of electrostatic collection of particles were also presented.

DISCUSSION OF RESULTS

A summary of the results for all molecular contaminants considered is presented in table V. Graphite-epoxy outgassing was predicted to result in a deposition thickness greater than 750 angstroms assuming 10% permanent sticking or residence of available outgassing products on HST Optical Telescope Assembly (OTA) surfaces. This conservative prediction, which exceeds the 5-year on-orbit budget of 20 angstroms by a factor of 35, can be attributed to the very large quantity of exposed graphite-epoxy (see table IV) in addition to its relatively high outgassing rate. The assumption of water being the major outgassing constituent of graphite-epoxy would greatly reduce the predicted thickness for HST; however, unprotected cryo-cooled surfaces (e.g., SIRTF optics) would experience the conservative or "worst case" deposition levels. The beta cloth enclosure material clearly contributes insignificant molecular contamination levels.

Figure 6 illustrates pressurization characteristics of the CSF from (a) beta-cloth outgassing and (b) EMU emissions during a normal 6-hr EVA shift, as a result of the simplified gas and Monte Carlo modeling techniques. It is apparent that EMU water emissions will "pressurize" the CSF even with substantial trap or vent area. Liquid hydrazine leaks can also result in elevated, however brief, internal CSF pressures.

The particle dislodgement/redistribution analysis resulted in very low obscuration of HST interior and exterior surfaces. A worst case prediction of less than 0.1% obscuration appears well below the 5% obscuration budget allocated for the OTA components as reported by MSFC personnel. The obscuration values were based upon dislodgement data of the type shown in table VI, a summary of data for the stated impact velocity, initial surface cleanliness, and beta cloth panel size.

The preliminary results obtained in the particle charging analysis indicated that the CSF surfaces will probably be only weakly charged due to the low charging level expected; particulates will most likely have to be charged in order to rapidly collect them using electrostatic techniques. The magnitude of the particulate attachment forces will have to be assessed in order to determine the effectiveness of direct neutralization of charged surfaces.

CONCEPTUAL SUBSYSTEM DESIGN

SUBSYSTEM DEFINITION

Both customer and contractor program documents have identified key functional requirements for the CSF contamination control subsystem (CCS). The top priority would obviously be to control all forms of contamination within the facility "to enable servicing of observatory class satellites and instruments with sensitive surfaces and systems." To accomplish this, provisions must be made for (1) measurement/monitoring of the internal contamination environment, (2) collection and disposal as appropriate to maintain acceptable levels, and (3) cleaning, refurbishment and cleanliness verification of components in need of such action. Part (2) of the functional requirement also implies that core SS requirements are met.

METHODS OF ACCOMPLISHMENT

Due to the abundance of contamination sources and their complexity of interactions associated with the overall environment, realization of these functional goals would require a comprehensive subsystem approach to the problem beginning with the design phase and continuing through the mission phase by considering operational alternatives which minimize the possibility of compromising servicing users. This subsystem approach can be divided into three general categories--design, operational, and hardware implementation controls.

The most important control associated with design efforts is the careful selection of hardware configurations and their materials of construction. This is true of the core Station as well as the CSF. Low outgassing and low particle generating or shedding materials are obviously preferred; special criteria may be in order for very large surfaces (such as the SBE). Also, cleanliness levels during ground processing and transport should be maintained to prevent additional contamination accumulation.

The design of a self-contained, low contamination generation potential EMU and space suit would reduce the significant contribution expected from the present system: in fact, a self-contained EMU is expected for IOC missions. In addition, the development and implementation of robotic capability would eliminate the "human" influence altogether.

Suspected temporal variations in the contamination environment due to intermittent and periodic sources suggest that judicious planning of highly contaminating events can reduce the chance of contaminating the CSF interior and/or its resident user. Closure of the CSF during events such as shuttle docking/departure, pressurized module dumping (especially modules which vent high molecular weight constituents), and other possible instances where the potential for contamination of the CSF is high, should be scheduled to prevent contamination of resident users and internal CSF surfaces. Periodic maintenance of the CSF itself may be required to reinstate its surfaces to an "acceptably clean" level.

The third category suggests the selection and implementation of contamination control devices dedicated to the CSF for the purposes of meeting the three functional provisions as stated previously.

SUBSYSTEM CANDIDATE HARDWARE AND TRADE ANALYSIS

In the interest of controlling both molecular and particulate forms of contamination, a comprehensive "shopping list" of control devices was created and is shown in the block diagram of figure 7. For the conceptual design phase, this shopping list acts as a collection of possibilities -- developed, flight proven, or strictly conceptual -- from which devices or combinations thereof could be selected to meet individual user requirements. The candidate hardware systems are subdivided into four groups as described in the following qualitative trade analysis.

Monitoring/Measurement System

As previously mentioned, translation of earth based monitoring criteria into space-applicable terms has not been well defined. Moreover, the measurement of contaminant species -- molecular or particulate -- with good spatial resolution in the CSF volume is thought to be a very difficult problem due to the low pressures involved. The devices shown in the measurement/monitoring block of figure 7, mass spectrometer/residual gas analyzer, ionization (pressure) gauge, and quartz crystal microbalance (QCM), have been developed to provide valuable information on the identification, concentration, and deposition rates of molecular species, and have been flown with reasonable degrees of success. Further investigation into the applicability of these devices for the CSF would be required prior to final hardware selection.

Representative and reliable measurement techniques of the particulate environment have not been identified to date. Light scattering and bright light illumination devices are possible real time monitoring methods, however, one would require extensive technology development and the other suffers from limited resolution. Cumulative monitoring using witness samples and subsequent counting, sizing, or other quantification of particulate levels and their effects can be implemented if pressurized evaluation laboratory space were made available.

Collection and Control System

Contamination which contributes to an unacceptably high level within the CSF requires some mitigating activity to attain the desired environment. Collection and/or control hardware can range from very basic and simple passive devices to very complex and expensive systems. Obviously, the most cost-effective solution is preferred so long as the environment is "within specification" and does not experience excursions from specified levels for extended periods of time.

Molecular contamination such as outgassing products, small hydrazine leaks ($\leq$1 cc), material processing product venting, and water dumps can, in theory, be collected using (1) cold plates, (2) sorption surfaces or beds, or (3) they can be controlled passively through the use of shields, baffles, and covers. Redirection of contamination is not considered an ultimate collection method, however, and further treatment or disposal would be required. Inert gas purges may be possible for very small unpressurized volumes; in most situations, creation of enough gas molecule collisions would constitute a major drawback for this method. Condensation of outgassing products and other high molecular weight species can be efficient at moderate temperatures (200 K to 300 K), however, water, hydrazine, and compounds with condensation temperatures below 200 K would require active cryogenic surfaces for efficient and predictable collection. Table VII summarizes key trade issues for these devices. Heaters may be used to prevent deposition onto a critical surface by decreasing the sticking probability of impinging contaminant molecules.

The particle charging analysis concluded that electrostatic collection of particles ranging in size between 10 and 500 microns was feasible inside the CSF. Inducement of surface charge on the particles and placement of oppositely biased collector surfaces (usually in plate form) would be required. Modeling results have indicated that a 15-fold reduction in the time required for a negatively charged particle to arrive at a neutral surface (2.5 hr) could be expected if the surface were biased (10 min for a +100 V plate). Filtration or associated techniques that rely on entrapment or inertial impaction typically require a controlled, directional flow of the gas to be cleansed.

Treatment/Storage/Disposal System

A nonventing CSF complicates the disposal of collected or redirected contamination, and creates the need for an independent system which will determine their ultimate fate. To date, nonline-of-sight venting paths are by far the most cost-effective and universally accepted method for expelling gaseous products for the majority of space vehicles. However, the unique environment of the Space Station and its many contamination control concerns dictate that this method may not be acceptable. This would then call for an alternate approach such as encapsulation and sealing of contaminants in containers and subsequent transport to an appropriate "waste holding area." Reduction of voluminous or large amounts of contamination may be considered to reduce spatial requirements for temporary storage.

An alternative to simple venting or storage of higher molecular weight or chemically reactive species is to breakdown their structure by physical/chemical methods. Media containing catalysts, reactants, or adsorption materials can result in conversion of such species to reaction products with lower condensation temperatures (such as water and carbon dioxide), and hence lower sticking probability on surfaces maintained at or near ambient temperatures.

Cleaning and Refurbishment

Studies have been performed to simulate atomic oxygen (AO) erosion for the removal of carbonaceous material from critical surfaces.* Other suggested methods include dry wiping by astronauts to remove particulate contamination and the use of high energy plasma electrons for molecular film cleaning. Methods that rely on EVA assistance are not recommended for sensitive components because of the molecular emissions and particulate generation potential associated with

*Perkin Elmer and General Electric studies.

the current EVA/EMU design. Robotic manipulation of cleaning equipment would virtually eliminate contamination introduced as a result of the cleaning process. In any event, surface cleanliness verification techniques applicable to the CSF environment would be needed if cleaning of surfaces with very low contamination budgets is performed.

CONCLUSION

The complex Space Station environment and the preliminary requirements for customer servicing of contamination-sensitive users and the core SS present unique contamination control concerns. Preliminary analysis has indicated the need for a comprehensive "subsystem" approach to address these concerns. In the area of requirements, criteria applicable to the unpressurized CSF environment are sorely needed; interfacing of servicing, user, and core SS requirements should also be accomplished stressing maximum commonality of criteria. Although the large size and the operations (EVA, moving mechanisms) associated with the multipurpose function CSF can result in an unfavorable contamination environment for sensitive users, preliminary design solutions have been identified. The evolution of the contamination control subsystem concept will depend upon careful CSF and core SS design considerations, coordination of operations between Space Station elements, and the development of a technically efficient and cost-effective contamination monitoring, collection, and disposal flight hardware system.

ACKNOWLEDGEMENTS

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TABLE I. SUMMARY OF SPACE STATION LEO ENVIRONMENTAL CONDITIONS

Environmental Parameter	Quantitative Description
Orbital characteristics	460 km altitude 28.5^{o} inclination
Atomic oxygen fluence (1)	
-RAM Directed	2.0×10^{21} atoms/cm^2-yr
-Non-RAM	2.5×10^{20} atoms/cm^2-yr
Solar UV radiation	
-Near (0.2-0.4 microns)	123 W/m^2
-Vacuum (<0.2 microns)	3 W/m^2
Debris flux, F (2)	Log F = -2.52 Log D - 5.46 (3)

(1) Normal solar activity assumed
(2) Debris at 500 km altitude
(3) D = diameter of debris (cm)

TABLE II. MISSION LIST FOR CUSTOMER SERVICING

Mission Designation	Mission Name	User Type (1)
SAAX 0004	SIRTF	FF
SAAX 0012	HST	FF
SAAX 0013	GRO	FF
SAAX 0016	Small Solar Physics (SMM MOD)	FF
SAAX 0017	AXAF	FF
SAAX 0022	Spartan Platform No. 1	FF
SAAX 0031	Hitchhiker No. 1	ATT
SAAX 0207	Solar Terrestrial Observatory (STO)	ATT
SAAX 0250	Hitchhiker No. 4 (ERBE) (2)	ATT

(1) FF - free flyer; ATT - station attached
(2) ERBE -Earth Radiation Budget Experiment

TABLE III. SUMMARY OF REQUIREMENTS FOR KEY SERVICING USER PAYLOADS

Vehicle	Type	Contamination Requirements/Sensitivities: Molecular	Particulate
HST	FF	- < 20 Å per 5 yr on-orbit (2) - 15 PPM HCs max (3) < 10E -5 torr amb pressure	- Class 100 through Class 100K (OTA exposure dependent) - Optics extremely sensitive
AXAF (1)	FF	- Sensitive to HC deposition	- Class 100 through 1000 (aperture open)
		- < 10E -5 torr amb pressure	- Class 10K (aperture closed)
SIRTF (1)	FF	- Mat'l outgassing rate <3.0 E-7 gm/cm^2/hr - MCD < 10E+11 molec/cm^2	- Class 300 for servicing
ASO/SOT	ATT	< 10 Å on mirrors	- Class 10K for instrument repair
STO	ATT	- Sensitive to H_2 and O_2	- None identified

(1) Payloads contain cryogenic surfaces
(2) No specific budget or allotment for servicing per MSFC
(3) HC - hydrocarbons

TABLE IV. LIST OF SOURCES CONSIDERED FOR INTERNAL SOURCE CONTAMINATION ANALYSIS

Material	Application	Quantity	Source Type (1)
Beta cloth	Enclosure material	15,000 ft^2(2)	M/P
Graphite epoxy	Support structure	5,000 lbs (~ 18,000 ft^2)	M
Electronic boxes	---	TBD	M
Wire insulation	---	TBD	M
Lubricants	Track/rail, motor drives	TBD	M/P
Hydrazine	Refueling	1 cm^3/disconnect	M
EVA/EMU	Servicing/maintenance	0.1 gm H_2O/sec activity 31.5 cm^3 air/min TBD particulate	M/P

(1) M - molecular; P - particulate

(2) Based upon 10.7 x 10.7 x 27.4 m (35 x 35 x 90 ft) CSF configuration

TABLE V. SUMMARY OF MOLECULAR TRANSPORT DEPOSITION AND PRESSURIZATION ANALYSIS FOR HST SERVICING

Contaminant Source	Contamination Parameter: Deposition Thickness On OTA Surfaces (angstroms)	Contamination Parameter: CSF Internal Pressure (torr)
EMU water dump (1)	(2)	$\frac{7 \times 10^{-4}}{\text{Trap area } (M^2)}$
EMU air leakage (1)	(3)	$\frac{1.1 \times 10^{-5}}{\text{Trap area } (M^2)}$
Hydrazine spill (1 cm^3)	(4)	1×10^{-4} (5)
Graphite-epoxy outgassing (6)	770	3.5×10^{-7}
Beta-cloth outgassing (6)	< 1	3.2×10^{-11}

(1) Based on current EMU design; IOC available waste collection unit for current EMU would eliminate source and subsequent deposition
(2) Extremely high on cold surfaces
(3) Very high on cryogenic surfaces without moderate venting or trapping
(4) Highly dependent on areas of cold surfaces
(5) Instantaneous pressure, dissipates rapidly
(6) Based on 14-day servicing mission

TABLE VI. RESULTS OF PARTICLE DISLODGEMENT ANALYSIS

0 Input Parameters: Impact Velocity - 60 cm/sec
Initial Surface Cleanliness - Level 750
Per MIL-STD-1246A
Beta-Cloth Panel Area - 150 ft^2

Particle Size Range (Mean Particle Dia in Microns)	NP_i (1) (No./ft^2)	Fraction Dislodged	NP_d (2) (No./ft^2)	TNP_d (3) (No.)
50-100 (75)	73,900	0.15	11,085	1.66E+6
100-200 (150)	5,700	0.75	4,275	6.41E+5
200-300 (250)	332	0.96	319	4.78E+4
300-400 (350)	54	0.99	53	8.02E+3
400-500 (450)	8	1.0	8	1.20E+3
500-700 (625)	5	1.0	5	7.50E+2
750 (750)	1	1.0	1	1.50E+2

(1) NP_i - Initial surface particulate level

(2) NP_d - Number of particles dislodged per unit area of beta-cloth

(3) TNP_d - Total number of particles dislodged per beta-cloth panel

TABLE VII. QUALITATIVE TRADE ANALYSIS FOR MOLECULAR CONTAMINANT COLLECTION DEVICES

Collector/Control Device Type	Advantages	Disadvantages
Cold Plate	Very high capacity Nonselective adsorption Current technology available	Large surface areas required Large facilities requirement (power, cryogen supply) Reliability concerns
Adsorption Media	Minimum facilities required Lightweight Regeneration possible	Low capacity Efficiencies varies with contaminant concentration May generate particles
Inert Gas Purge with Filtration	Technology available Effective for suitable geometry Makes use of existing user purge hardware	Large gas volumes required CSF plumbing required Limited applicability
Passive Devices (shields, vents, baffles)	Very low cost Flight proven	Not an ultimate destruction method Devices may be large

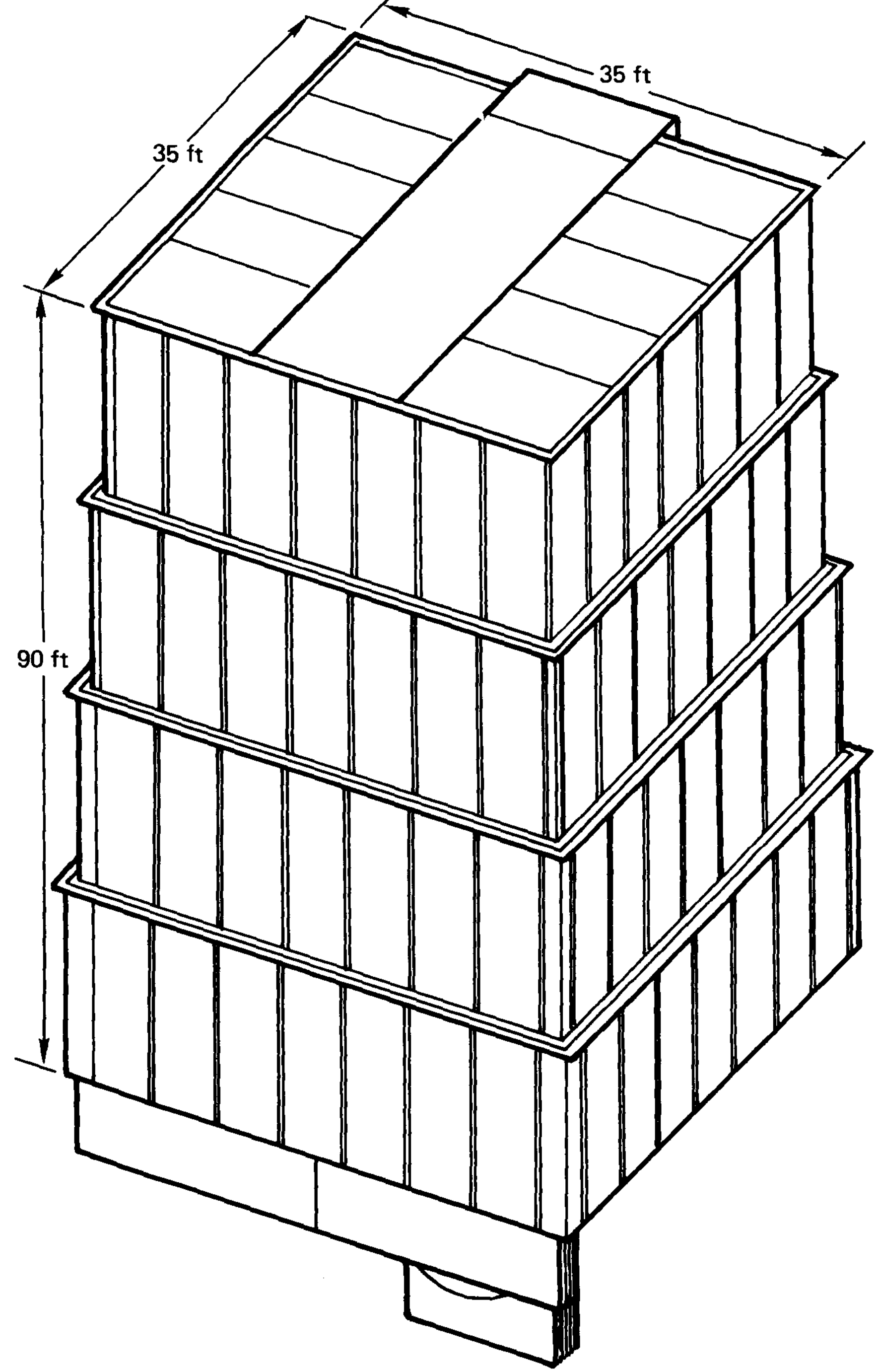


FIGURE 1. CSF -- EXTENDED MODE

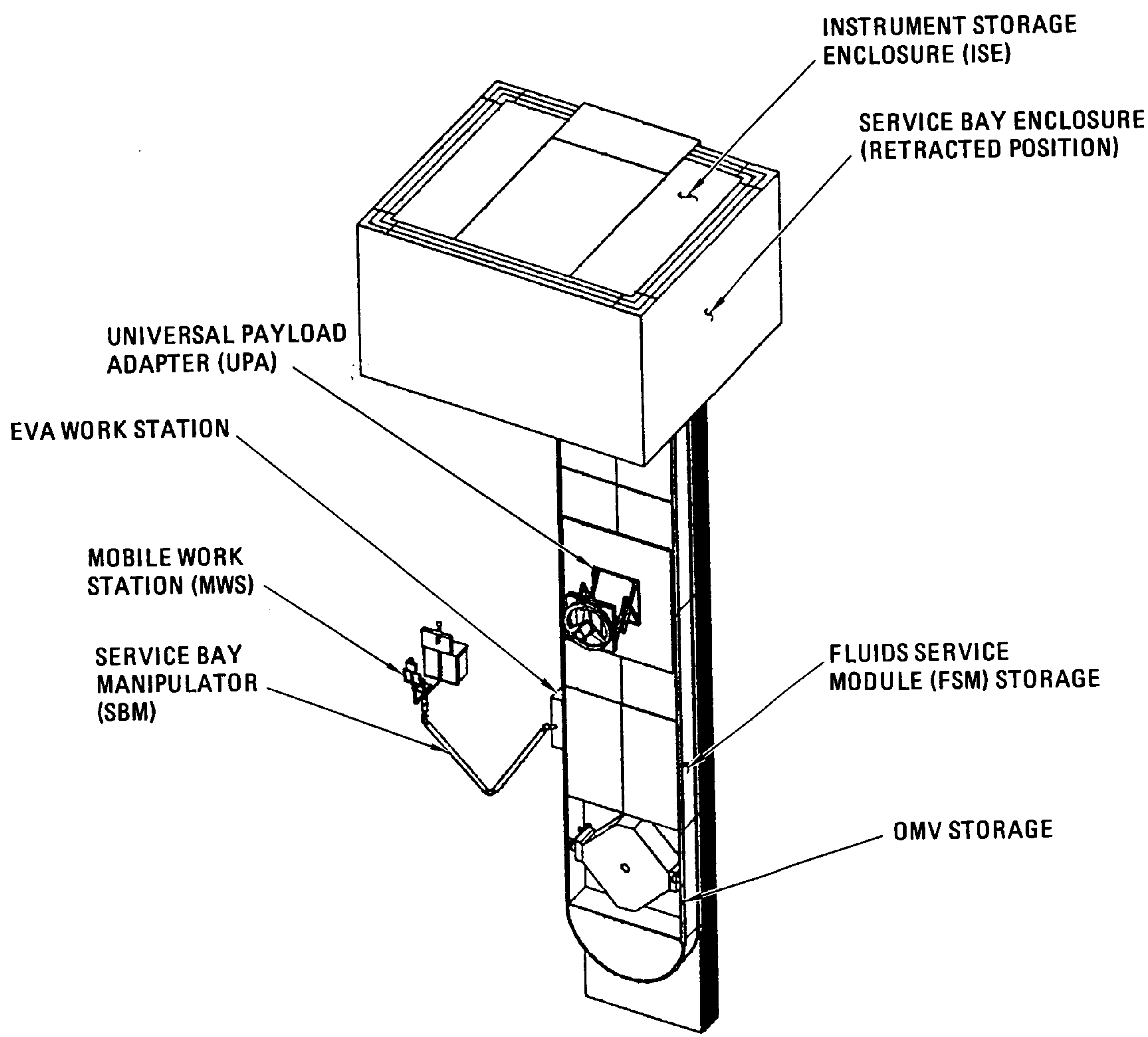


FIGURE 2. CSF RETRACTED MODE SHOWING VARIOUS SERVICING MECHANISMS

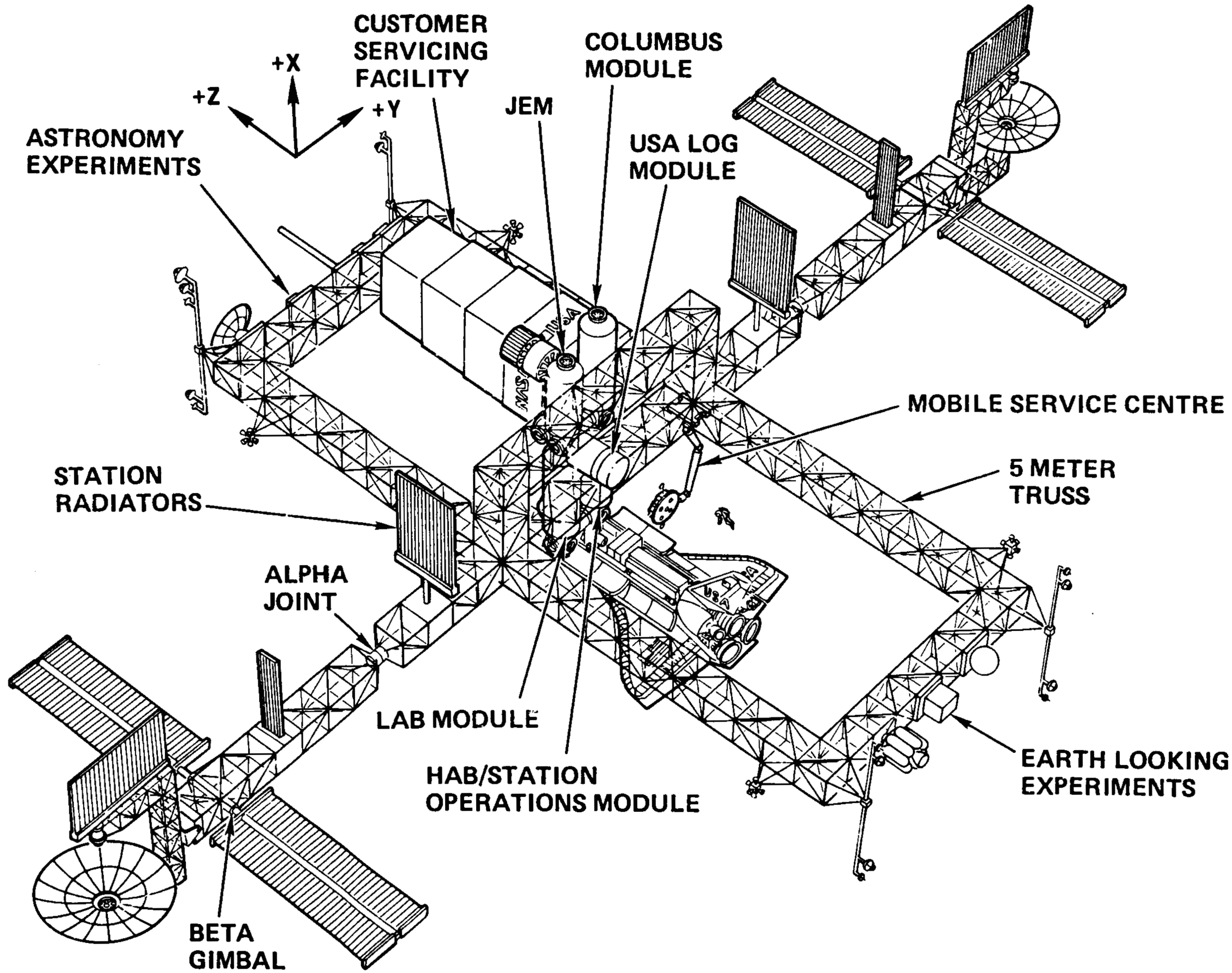


FIGURE 3. SPACE STATION DUAL KEEL CONFIGURATION

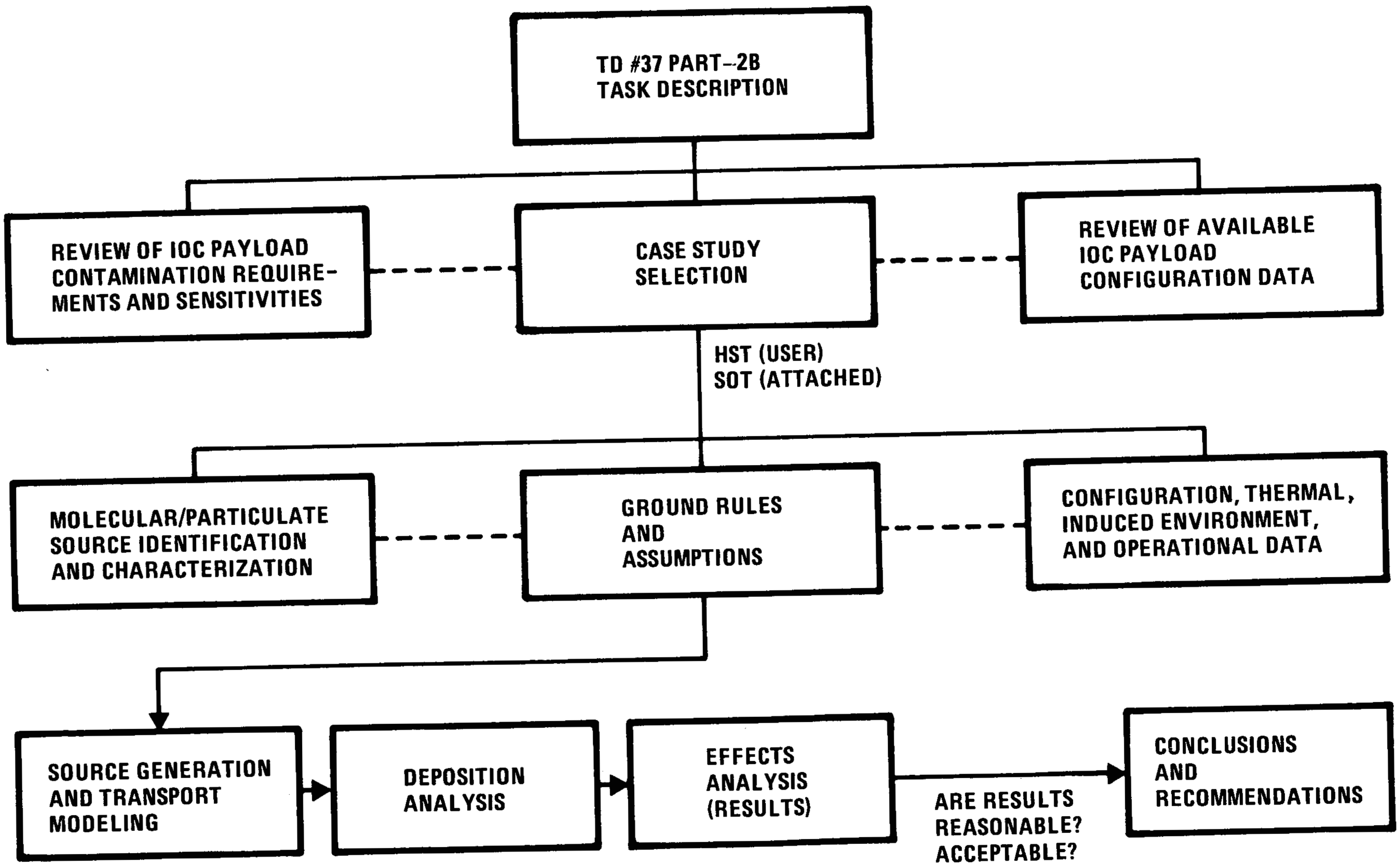


FIGURE 4. FLOW DIAGRAM OF SERVICING AREA CONTAMINATION ANALYSIS -- INTERNAL SOURCES

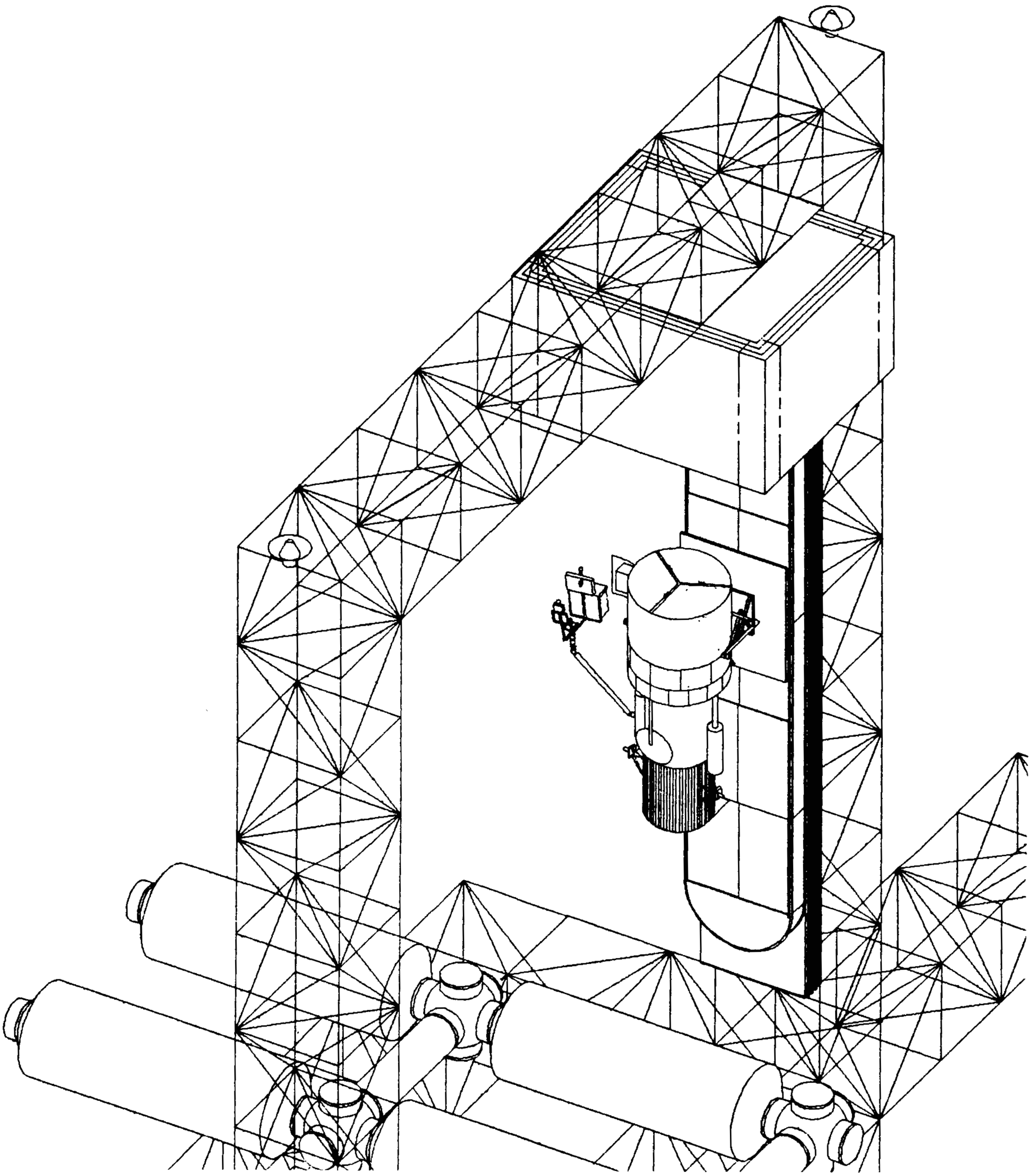


FIGURE 5. SERVICING HST IN THE CSF

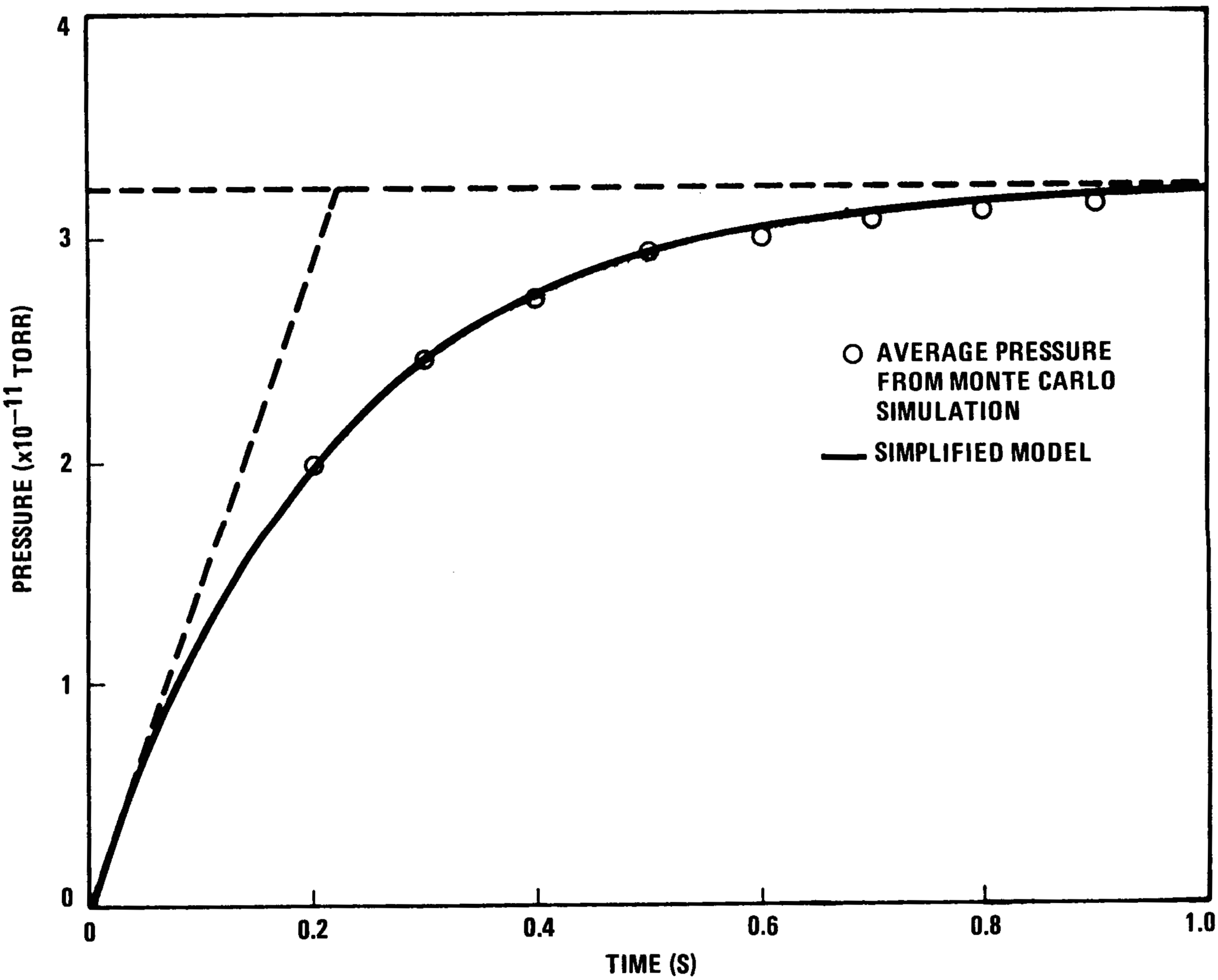


FIGURE 6a. TRANSIENT PRESSURIZATION OF CSF BY BETA-CLOTH OUTGASSING

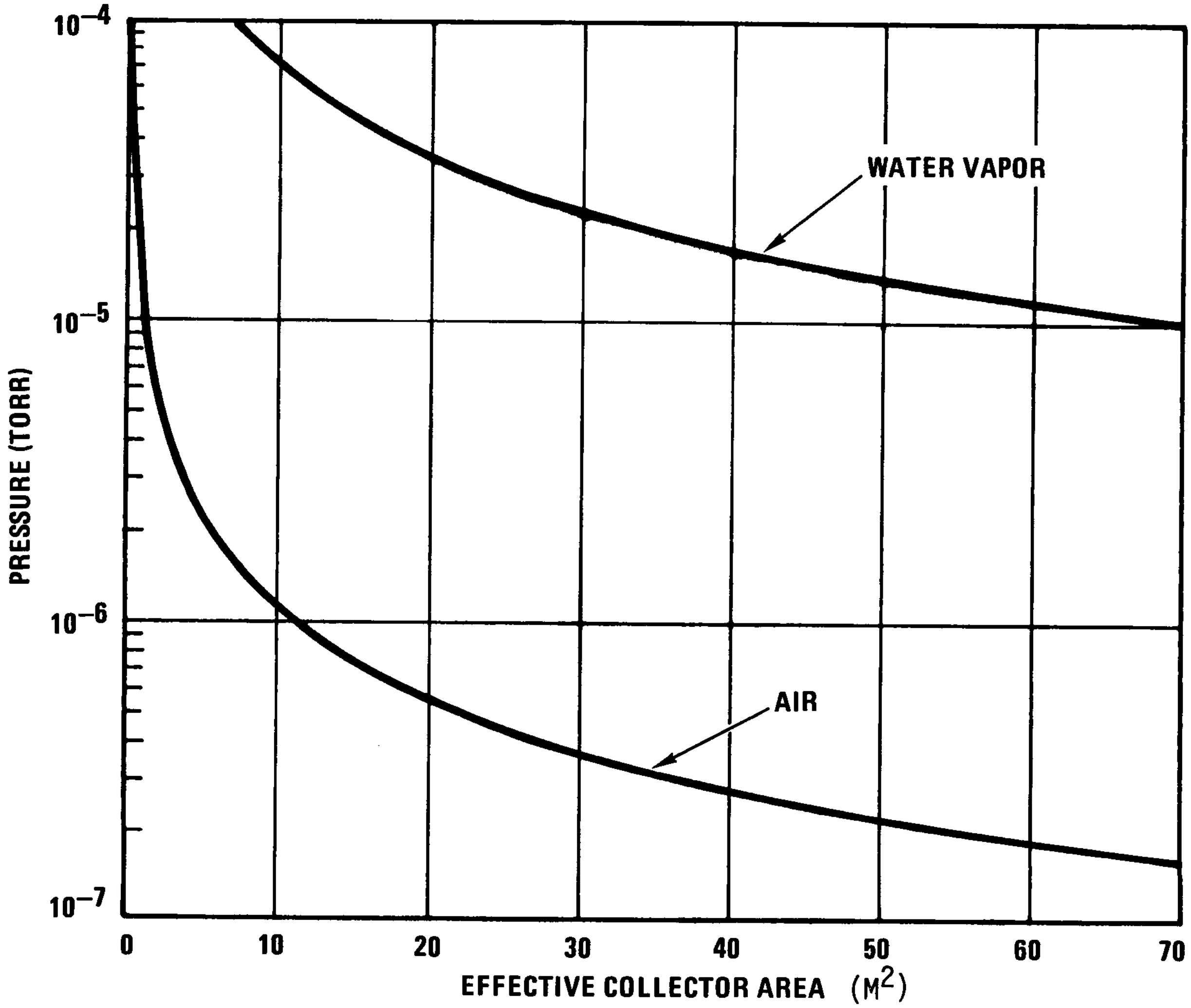
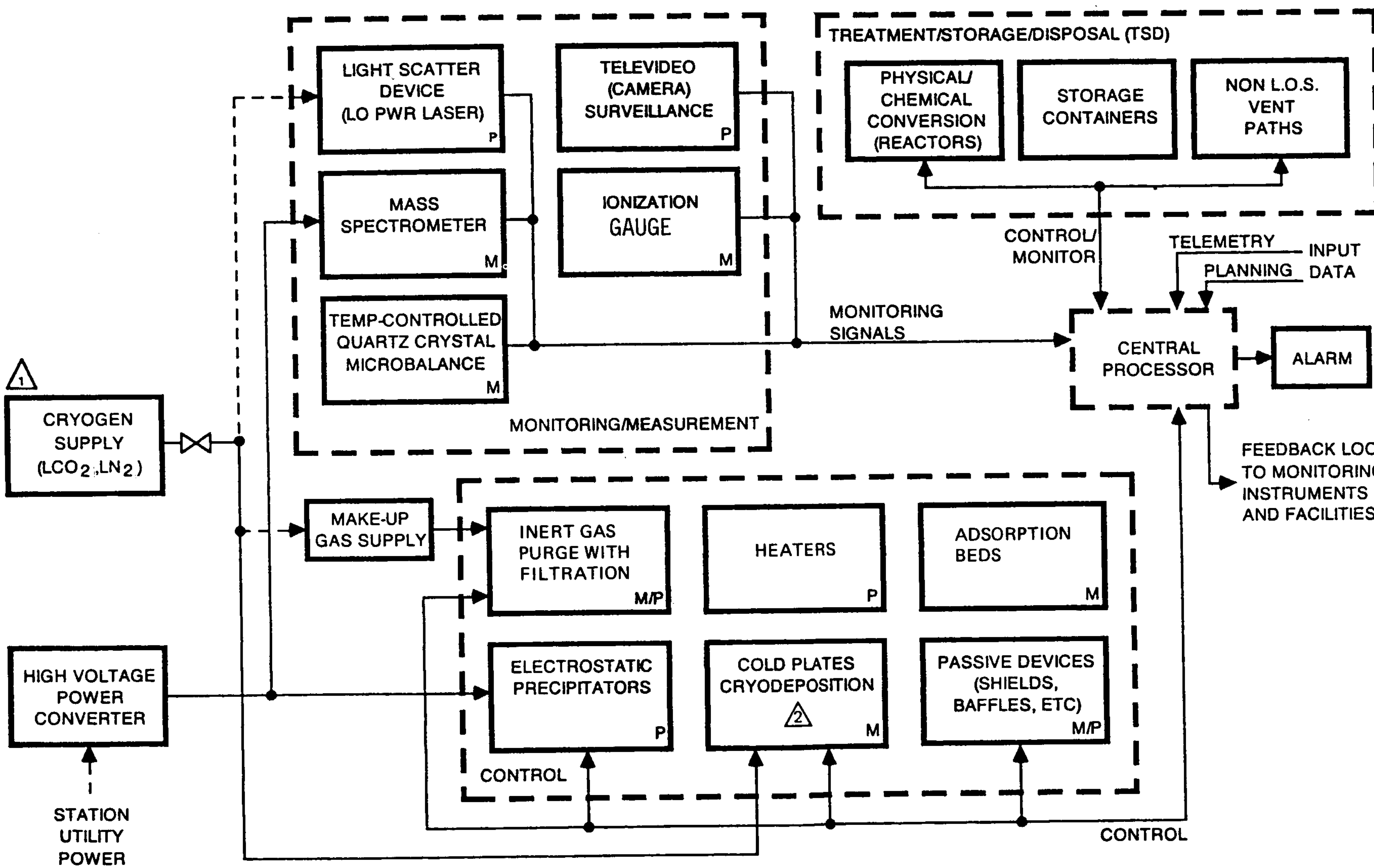


FIGURE 6b. CSF PRESSURIZATION FROM EMU WITH ACTIVE COLLECTION



"M" IS MOLECULAR
"P" IS PARTICULATE

1. OTHER CRYOGEN SOURCE OR THERMAL CONTROL LOAD (NH_3)(LHe) MAY BE USED IF AVAILABLE
2. REFRIGERATION CYCLE REQUIRED

FIGURE 7. BLOCK DIAGRAM OF PROPOSED HARDWARE FOR CSF CONTAMINATION CONTROL SUBSYSTEM