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Gas-Grain Simulation Facility (CGSF) Volume II Conceptual Design Definition

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Table of Contents

List of Figures

List of Tables

List of Acronyms

C&DM - Control and data management
cm - centimeter
CNC - Condensation Nuclei Counter
CRES - Corrossion Resistant Steel
D/A - Digital to Analog
DMS - Data Management System
FTIR - Fourier transform infrared
g - one earth gravity
GGSF - Gas-Grain Simulation Facility
ISPR - International Standard Payload Rack
kg - kilogram
kw - kilowatt
kw$_{th}$ - thermal kilowatt
LSE - Laboratory Support Equipment
μg - micro-g
m - meter
MDM - Modulator/De-Modulator
mm - millimeter
NASA - National Aeronautics and Space Administration
N/A - Not applicable
PWB - Printed wire board
R&T - Research and Technology
RTD - Resistance Thermal Detector
S&T - Science and Technology
SAMS - Space Acceleration and Measurement System
SCSI - Small computer system interface
SSF - Space Station Freedom
SSS - Space Shuttle System
STP - Standard temperature and pressure
TBD - To be determined
TPDA - Tertiary Power Distribution Assembly
UV - Ultraviolet
VES - Vacuum Exhaust Subsystem
VRS - Vacuum Resource Subsystem

1 SUMMARY

This document is Volume II of the Final Report for the Phase A Study of the Gas-Grain Simulation Facility (GGSF), and presents the GGSF Conceptual Design. It is a follow-on to the Volume I Facility Definition Study, NASA report CR177606. This report has been prepared under contract number NAS2-13408 for the NASA/Ames Research Center.

This report delineates the development of a conceptual design for a Space Station Freedom (SSF) facility that will be used for investigating particle interactions in varying environments, including various gas mixtures, pressures, and temperatures. Its not possible to study these experiments on earth due to the long reaction times associated with this type of phenomena, hence the need for extended periods of micro-gravity. The particles types will vary in composition (solids and liquids), sizes (from submicrons to centimeters), and concentrations (from single particles to 10^{10} per cubic centimeter).

The results of the experiments pursued in the GGSF will benefit a variety of scientific inquiries. These investigations span such diverse topics as the formation of planets and planetary rings, cloud and haze processes in planetary atmospheres, the composition and structure of astrophysical objects, and the viability of airborne microbes (e.g., in a manned spacecraft).

The GGSF is scheduled for initial operation on SSF during the man-tended phase. The initial Core Facility, with limited capabilities, planned for launched in 1998, and the final Mature Facility, with full capabilities, will be launched in 2002. The upgrade from the Core Facility to the Mature Facility includes: increased computer power for real time decisions; additional test chambers to support very low and very high temperature experiments, as well as those requiring hard vacuum; additional data acquisition instrumentation; incorporation of gas mixing and humidifying to produce more complex atmospheres; and additional particle generation and manipulation equipment.

Figure 1 illustrates a conceptual design of the GGSF, shown schematically in Figure 2. The GGSF provides an interchangeable test chamber for experimentation, several particle generators for various solid and liquid sample types, instrumentation for determining experiment results, electronics for facility control and data handling, a power system for conditioning and distribution, a gas handling system for providing a controlled test mixture and pressure, all packaged into a standard SSF rack for transportation and operation. The components are removable for replacement of expendable materials, technology upgrades, repairs, and general maintenance.

In Volume I of this report (NASA CR177606), the science and technical requirements were evaluated for each of the GGSF experiments in section 3, and formulated into facility functional requirements presented in section 4. Volume II reports the results of the expansion from requirements into a facility conceptual design that fulfills them.

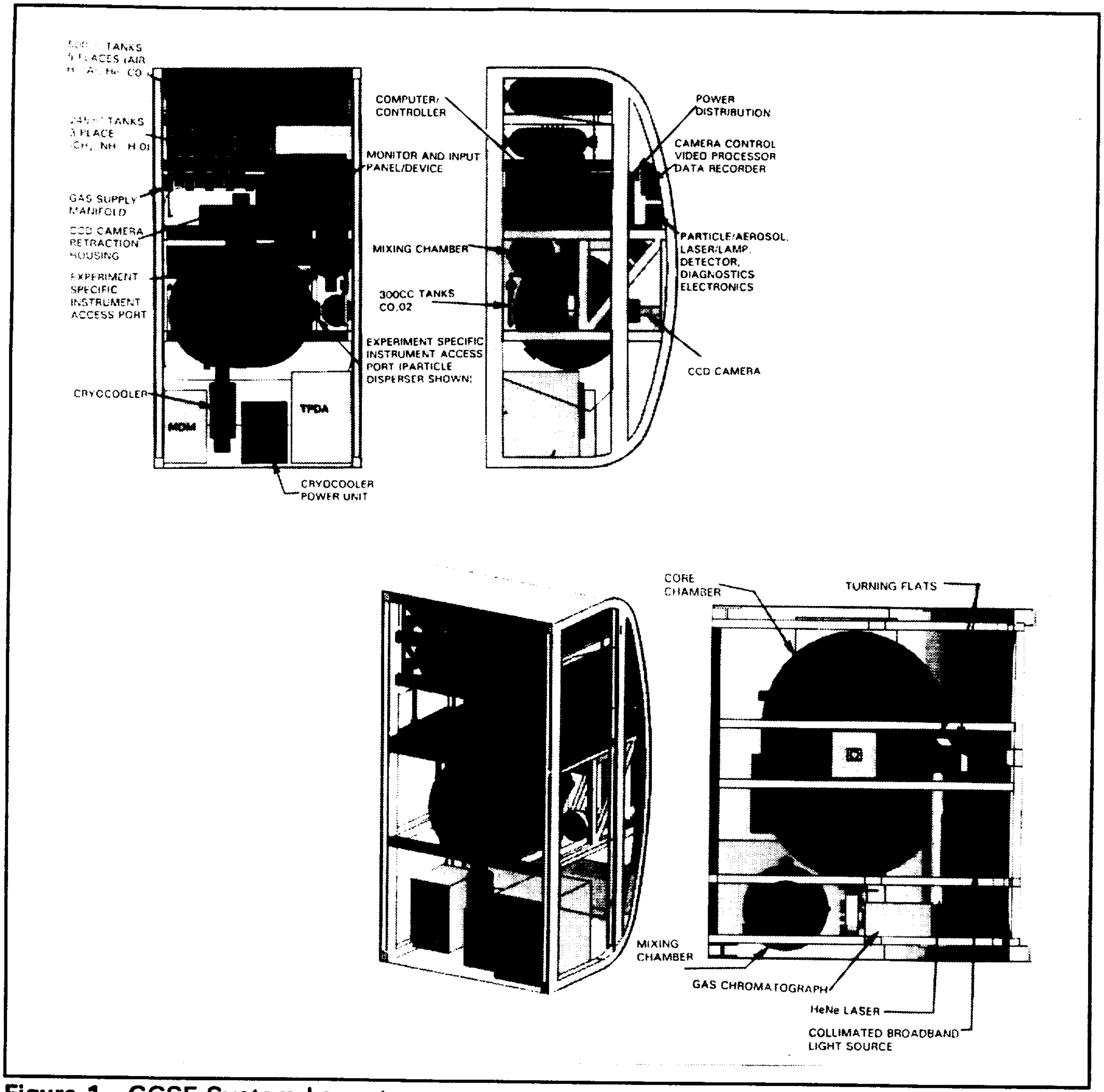


Figure 1 - GGSF System Layout

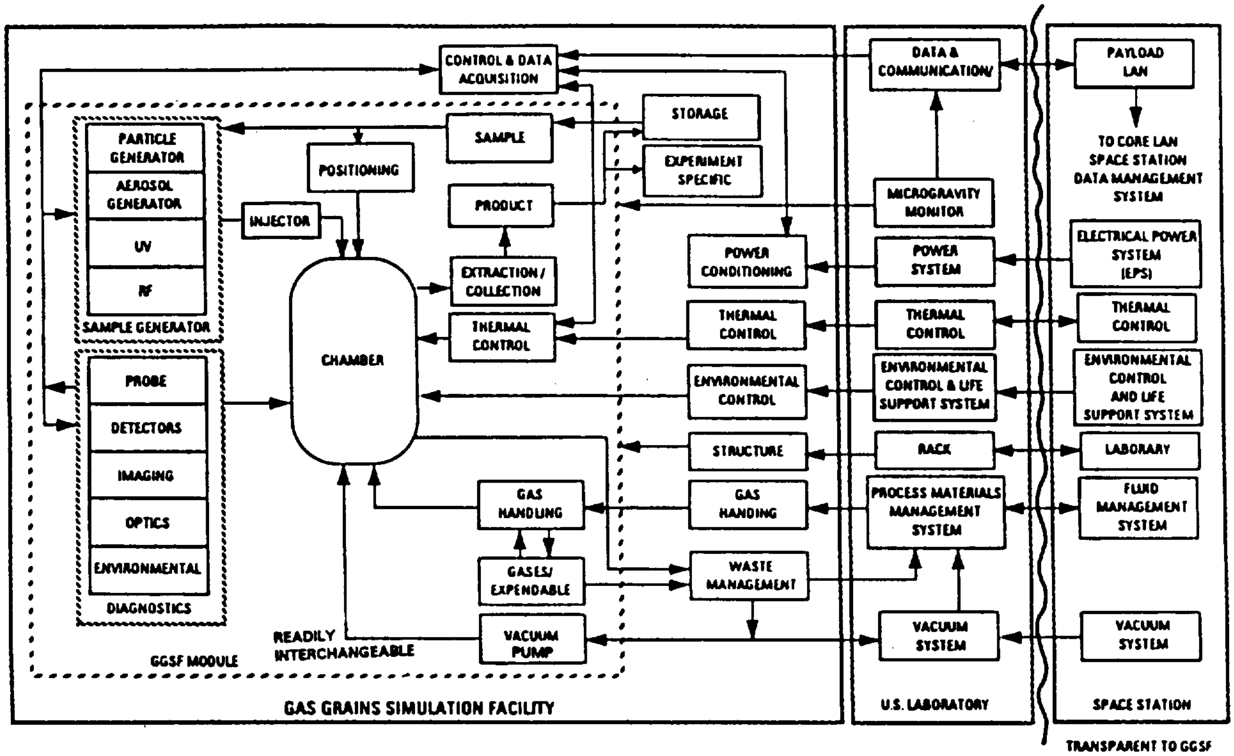


Figure 2 - GGSF Phase A System Schematic.

2 SUMMARY OF SYSTEM REQUIREMENTS

The GGSF S&T requirements are defined and presented in detail in the Volume I, Stage 1 - Facility Definition Studies, NASA CR177606. A summary of these requirements are shown here in Table 1. In order to perform the GGSF experiments on Space Station Freedom, the requirements of this platform must be met. SSP30000 is the primary document that defines interfaces and platform requirements for payloads on SSF. At the time of this study SSF requirements were undergoing Preliminary Design Review. These include mass properties, volume, power, thermal control, data handling, facility monitoring, and other related requirements. Safety requirements are defined in NSTS1700.7 for flight safety, and KHB1700.7 for ground safety.

Since the GGSF will be initially deployed as a Core Facility which is operational during the man-tended phase of SSF, pre-programmed automation and remote control capabilities will be required to perform repeated experiments.

The Core Facility will have limited capabilities in control of the chamber environment and particle analysis. The progression to a fully capable Mature Facility will incorporate more flexible and capable subsystems, including gas handling and mixing, diagnostics, and the control computer and software. These upgrades will allow for more human interaction in designing and modifying experiments in "real time".

The GGSF is divided into subsystems that will fulfill the functional requirements of the system. Table 2 breaks the GGSF into it's subsystems and summarizes the functional requirements of each.

Table 1 - GGSF Science and Technology requirements summary as derived in Volume I.

Chamber pressure	From 10^{-10} to 3 bars, with a desire to reach 11 bars
Chamber temperature	From 10 to 1,200 K, with a desire to reach 4 K
Chamber volume	From 1 cm^3 to several hundred liters, various geometries
Particulate matter type	Liquid aerosols, solid-powder dispersions, soot from combustion, high-temperature condensates (nucleation of metal and silicate vapors), low-temperature condensates (ices of water, ammonia, methane, or CO_2), a single liquid droplet, a single or a few particles, *in situ* generated particulate by UV or RF radiation, or by electrical discharge
Particulate size range	From 10 nm to 3 cm
Sample preparation and handling	Sample positioning and levitation
Particulate concentration	A single particle to 10^{10} particles per cm^3
Gases required	Air, N_2, H_2, He, Ar, O_2, Xe, H_2O, CO_2, CO, NH_3, CH_4, and more experiment-specific gases
Diagnostics required	In-line optical systems and off-line sample analyses, including measurements of the grain size distribution, the number density (concentration), optical properties such as index of refraction, emission and absorption spectra, imaging measurement of the grain's strength, mass, density, electrostatic charge, and geometry, collision parameters, including particle kinematic parameters before and after the collision
Experiment duration	From a few seconds, for collision experiments, to weeks, for the biology experiments
Automated facility control and management	Operation of the facility during man-tended phase.

Table 2 - GGSF Subsystems and Functional Requirements.

Subsystem	Functional Requirements
Chamber	• Provide working volume of up to 67 liters to conduct experiments • Provide controlled temperature environment between 10K (4K desired) and 1,200 K • Provide controlled pressure environment between 10^{-10} to 3 bars • Provide interfaces for diagnostics, sample insertion & removal, gas fill, evacuation line, power & data lines
Sample Generation and Manipulation	• Generate and disperse sample materials into the chamber, minimizing carrier gas, as follows: - Disperse solid particle clouds from 0.01 to 1,000 μm at concentrations from single particle to 10^8 cm^{-3} - Create aerosols of various solutions in sizes of 0.1 to 50 μm at concentrations from 300 to 10^6 cm^{-3} - Form and position a single particle or a liquid droplet in size from 1 to 10,000 μm - Form soot and other "smokes" from the combustion of hydrocarbon fuels and other materials - Generate *in situ* samples by UV, RF radiation or E-discharge - Create condensates and ices of H_2O, CO_2, CH_4, NH_3 in sizes of 0.01 to 2,000 μm at concentrations from 1 to 10^8 cm^{-3} - Vaporize and create condensates of metal and silicate vapors ranging in size from 0.01 to 100 μm at concentrations from 10^6 to 10^{11} cm-3 • Allow for an automated TBD number of experiment repetitions with the same or different sample material • Provide means for single particle/droplet positioning & levitation • Provide means for particle acceleration to affect collisions
Diagnostics	• Characterize particles including measurements of size distribution, number density, and optical properties • Measure extinction, angular & spectral scattering, and polarization of light passing through sample cloud • Provide particle count and size distribution for sub-micron particles at low concentrations • Provide imaging capabilities • Provide access and define interfaces for in-chamber and experiment-specific diagnostics • Measure chamber pressure over operating range, chamber wall temperature at 3 locations, chamber interior temperature over operating range, g-level in 3-axes down to 10^{-6} g, gas composition and humidity
Gas Storage and Mixing	• Provide gas storage and mixing capabilities • Provide plumbing and necessary hardware for a controlled delivery of gas mixtures into the chamber
Waste Management	• Provide interface between the SSF VRS/VES and the GGSF subsystems • Remove particles and toxic/corrosive gases from the effluent • Provide storage for waste and expended filter/scrubber cartridges • Provide health monitoring capability TBD for the Waste Management subsystem
Sample Collection and Storage	• Provide sample extraction/removal capability • Store sample, including TBD environmental controls for sample preservation such as temperature, shock
Power	• Conditioning and distribute total power of 3 kW for the GGSF subsystems • Provide conversion from SSF 120 Vdc to 8, 18, 28 Vdc and 115 Vac at TBD level each
Electronics	• Provide experiment monitoring, control, and automation capabilities • Provide data acquisition, storage (TBD Mbyte) and analysis capability • Provide interface with SSF DMS via MIL-STD-1553 and FDDI • Monitor the engineering state-of-health of GGSF • Provide temperature control for avionics and electronics assemblies and subsystems
Structure	• Provide Support structure compatible with the ISPR accommodations • Store replaceable/interchangeable subsystems and assemblies for TBD period of scheduled experiments • Provide interface to the U.S. Module avionics air, cooling water systems, nitrogen, etc.

3 KEY ENGINEERING PARAMETERS

This section provides a summary of engineering criteria resulting from the requirements developed in Volume I, NASA CR177606. In Volume I, science and technical requirements were evaluated for each of the GGSF experiments and are discussed in section 3. In Vol I. science and technical requirements were developed into facility functional requirements in section 4. Design criteria are defined at the system and major subsystems levels below.

3.1 GGSF System

The facility design criteria are the result of an assimilation of three major sources of requirements.

- Experiment requirements derived from the science requirements in Volume I.
- SSF requirements and restrictions on mass, volume, safety, resource availability (such as power, vacuum, cooling, tools), LSE, operator availability, transportation for hardware delivery and re-supply, and general manned-space logistics. These are defined in SSP30000.
- General engineering requirements for fabrication, reliability, human interaction, quality control, etcetera.

Figure 3 is a summary of the elements that are considered in the GGSF design. The major general system design considerations are listed in Table 3. These criteria apply to the GGSF system design, and must be considered at all subsystem, assembly, and component levels of design as well.

The mass properties is limited by the Space Shuttle transportation requirements, to 500 kg not including the ISPR. This value must include 2 required units, the MDM and TPDA, which are used on all SSF facilities. Additional mass can be transported to SSF separately, but would require shipping fixtures compatible with the transportation system. Power consumption for SSF Facilities is limited to 12 kw, available from two 6 kw sources.

The facility can use fluid and avionics air for thermal control. Fluid loops at 40F and 65F are available, but the 15.2 kw_{th} must be shared by all payloads. The avionics air can carry up to 1.2 kw_{th}, but with a maximum of 3.6 kw_{th} for all payloads combined. These limitations drive the allowable thermal losses of the warmer assemblies, such as a heated experiment chamber.

Data acquired by the experiment needs to be transmitted to earth for use by the science community. This can be accomplished by a variety of methods.

- The data can be recorded on tape, flash card, or other storage media for later return to earth. This precludes real-time monitoring or experiment modifications as during the man-tended phase of SSF.

- The data can be transmitted through the 1553 data management bus on the ISPR. This will require sharing of the ground link with other SSF payloads, probable data storage until the ground link is available, and extra on-board data compression. However this option results in close-to-real time monitoring and possibly remote experiment control.

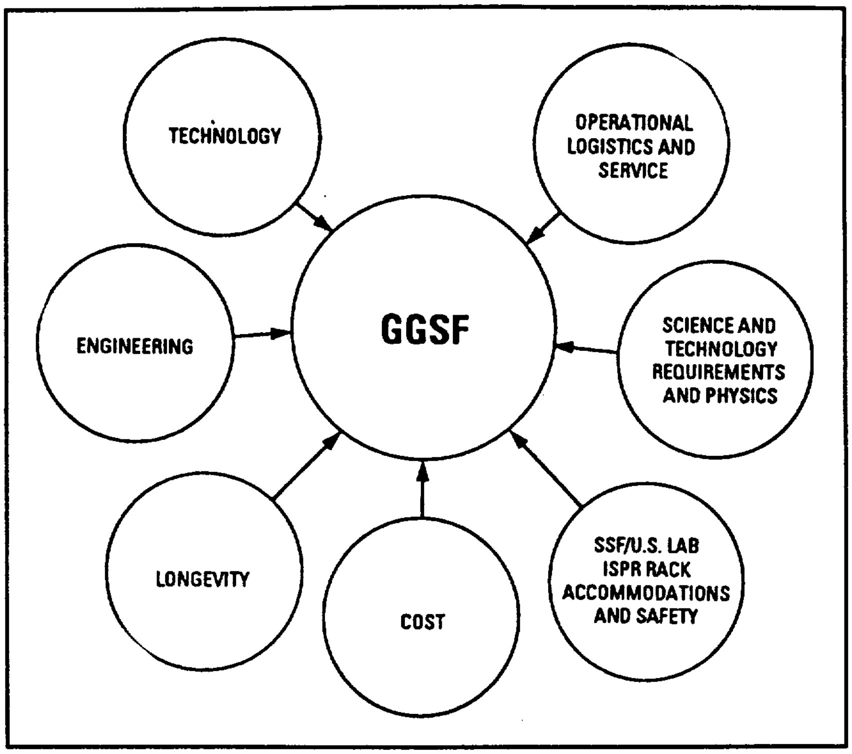


Figure 3 - Elements of the GGSF Design.

The GGSF will need internal housekeeping and monitoring capabilities. The payload status is reported to the SSF Payload Network, which checks for faults or hazards that are reported by the facility, and the SSF Payload Network may respond by shutting down the experiment, or with other necessary actions.

SSF is developing Laboratory Support Equipment (LSE) that GGSF experimenters may be able to use. LSE is shared by all SSF payloads, and cannot be dedicated to an experiment. Some LSE that is currently planned for SSF that may be useful to the GGSF users includes cleaning equipment, stereo microscope, refrigerator, a micro-mass measurement device, still cameras, -20C freezer, camera locker, video camera, film locker, portable glove box, general purpose hand tools, freezer for cryogenic storage, glovebox, and workbench.

Safety requirements for the GGSF are derived from those for ground safety in KHB1700.7, Space Shuttle transport safety and on-orbit manned environment safety in NSTS1700.7. Table 4 shows areas of general safety concern for the GGSF mission. An additional safety requirement defined in SSP30000, is fire detection and suppression capabilities for on-orbit in both operating and non-operating conditions. These functions are tied into the SSF fire control system.

Table 3 - Design considerations for the GGSF System.

Human Engineering for zero-g operations	● requires special resources such as hand and foot holds, protective switch covers, valve locks, panels and covers that lock closed and opened, tethered and captured hardware and tools ● facility must be able to withstand kick loads without damage of unplanned activations ● provide alignment rails, quick-connects, easy access, and minimal affect to other parts when removing or replacing interchangeable modules ● protect operator from extreme hot or cold surfaces, laser light beams, and sharp objects ● operator friendliness
Experiment isolation from other spacecraft operations	provide isolation of vibration, heat, electromagnetic radiation, and random light
Off-facility storage	identify space requirements for items requiring off-facility storage, such as samples, expendable supplies, and interchangeable items
Special Tool requirements	provide required tools for installation, maintenance, repair, or operation of the facility which must be included as part of the payload
Zero-g requirements	true static acceleration will exist on the order of 10^{-4} g. Other acceleration sources will be attitude correction systems, other spacecraft systems (fluids flowing, valves actuating, etc), and personnel moving around
Installation and removal from vehicle	package needs to fit through available openings, and be stored in available locations
Lifetime	● the payload can sit in the orbiter(on or off the launch pad) for months prior to launch ● a 20 year on orbit minimum usage is expected
Data transfer to experimenter	transfer and storage of hard data and samples, e.g. space requirements, containment, and environmental protection
Upgrade-ability	the components, assemblies, and subsystems should be removable for replacement with newer technology as it becomes available; this applies specifically to control and data acquisition electronics, diagnostic tools, and particle generation devices.

Table 4 - General Safety Concerns for the GGSF Mission.

Safety in Space Operations	Hazardous conditions such as: • high potential energy storage (pressurized containers, explosives, springs) • flammability of materials, should a fire break out • ignition sources, should a flammable atmosphere develop • contaminated breathing environment resulting from leakage of stored gasses, off-gassing of materials, combustion products, or vapors • particle contamination in which small drifting particles could be inhaled, ingested, or get into the eyes • radiation sources (lasers, microwaves, etc) that can damage sight, hearing, or other body functions, or disrupt spacecraft functions or other experiments • electromagnetic radiation (interference and compatibility) which can affect other experiments, spacecraft computers, and communications • rapid safe-mode capability to support emergency situations
Safety in space transportation	Hazardous conditions such as: • structural failure resulting in loose items that can damage the transporting vehicle, injure personnel, or damage other payloads. • high potential energy storage (pressurized containers, explosives, springs) • flammability of materials, should a fire break out • off-gassing materials or leaking stored gases that can produce explosive or contaminating environments • ignition sources, should a flammable atmosphere develop • electromagnetic radiation which can affect spacecraft computers and communications
Safety in ground operations	hazardous conditions such as: • high potential energy storage (pressurized containers, explosives, springs) • processes required for preparing experiment for transport, such as filling gas bottles, decontamination, ground testing, and installation into the launch vehicle

3.2 Chamber Subsystem

The science and technical requirements, and trade-offs for the Chamber Subsystem was defined in Volume I, section 4.1. The design uses four chambers to meet the experiment requirements. The majority of experiments can be accomplished in the Core Chamber. Other chambers will fill the requirements of extremes in temperature and pressure. Table 5 indicates the summarized requirements that resulted in four chambers, and how those chambers fill the requirements. A fifth chamber is listed as a possible low-risk, low-cost option that can meet the needs of room temperature experiments. The experiment compatibility with the chambers is shown in Table 6. As indicated, some of the experiments are partially compatible with more than one chamber.

Table 5 - Chamber requirements and application.

Chamber	Designation	Volume, cm^3	Temperature Range, K	Pressure Range, Bars
1	Large volume (core)	67,000	150 - 400	10^{-6} - 1
2	Low temperature	4,200	60 - 400	10^{-6} - 3
3	High vacuum	4,200	60 - 400	10^{-10} - 1
4	High temperature	8,200	Cabin - 1,200	10^{-6} - 1
5	Ambient	TBD	Cabin	10^{-6} - 1

A summary of the general chamber design considerations is shown in Figure 4. Some additional engineering criteria for the chamber are:

- The ability to have several directional views into the chamber, resulting in the need for multiple viewing ports for diagnostics.
- The desire to have as long a travel distance as possible between the point of particle generation and the opposite wall, indicating as large a dimension as possible in one direction.
- the ability to be opened for cleaning and installation of additional instruments.
- a desire to inject samples, then manipulate them, resulting in at least two ports for the users to utilize as required.
- light weight, which dictates hemispherical ends for optimum pressure vessel design.

These criteria are utilized in determining the design described in section 4.3.1 of this volume.

Table 6 - Experiment/Chamber compatibility

Key: ◆ = compatible ▣ = incompatible

Experiment No.	Chamber				
	Core	Low Temperature	High Temperature	High Vacuum	Ambient
1	◆ (T)	◆ (T)	◆ (T)	▣	
2	◆	◆	◆ (T)	▣	
3	◆	▣	▣	▣	
4	▣	◆	▣	▣	
5	◆	◆	◆ (T)	▣	
6	▣	◆	▣	▣	
7	◆ (T, P)	◆	◆ (T, P)	▣	
8	▣	◆	▣	▣	
9	◆	◆	◆	▣	
10	TBD	TBD	TBD	TBD	
11	◆	▣	▣	▣	
12	◆	◆	▣	▣	
13	▣	◆	▣	▣	
14	◆	◆	◆ (T)	▣	
15	▣	▣	◆	▣	
16	◆ (T)	◆ (T)	◆ (T)	▣	
17	▣	▣	▣	◆	
18	▣	◆	▣	▣	
19	▣ (*)	▣	▣	▣	
20	▣ (*)	▣	▣	▣	
21	◆	▣	◆	▣	

Only partial compatibility due to range mismatch in temperature (T), Pressure (P), volume (V) range
(*) Investigator expressed that size limitation is acceptable.
Note: Chamber geometry not considered as long as the volume is within range (i.e., an experiment-specific geometry chamber may be inserted inside one of the primary chambers listed here)

3.3 Sample Generation Subsystem

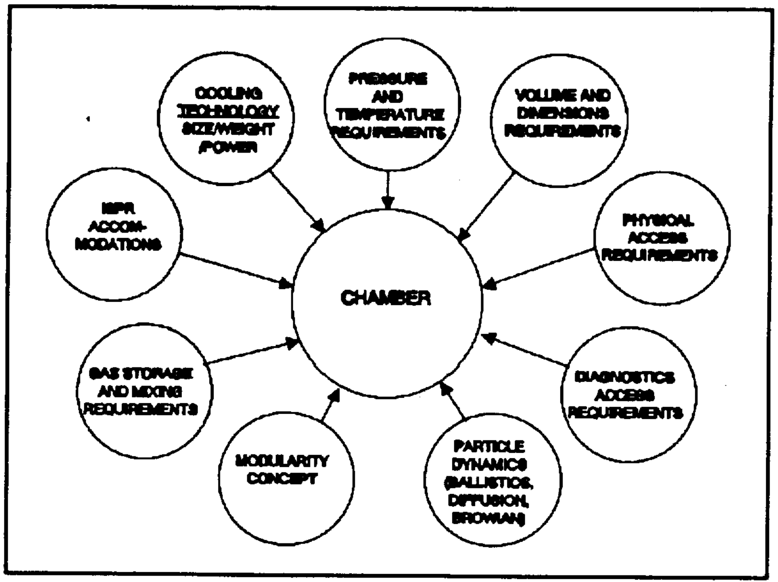


Figure 4 - Elements to Consider for the Chamber Design.

Many types and sizes of samples are required for the GGSF. Volume I, section 4.2 described the requirements, as well as the resulting generator types needed to meet the requirements. The types, size and quantity of the samples to be generated lead to separate devices for small and large particles, solid and liquid particles, smoke and soot, condensation, and radiative conversion of molecular structures of existing particles. This broad range of generator types will require further Research and Technology (R&T) studies that will result in designs for particle dispersion experiment groups. Section 4.3.2 in this volume describes the particle generator design work covered during this phase A study.

Some additional criteria that apply to the particle generators of this subsystem include:

- the need to fit into a common chamber access port.
- the ability to utilize common electronics for control and power.
- the capability of providing various particle types and concentration wherever possible.
- fitting into the generator storage drawer.

The intent of these generator criteria is to include incorporation of the commonality which allows future development of these devices for customized experiments. This flexibility will allow accommodation of many generator types that cover a broad range of experiments, while utilizing common chamber access ports, and facility power and control electronics interfaces.

Several types of sample generators are depicted in Figure 5. The shaded blocks indicate those that are most adaptable to the GGSF application. These modules generate a wide variety of particles, either singularly, or as clouds. The particles can be condensates, liquids, ices, or other solid grains. Separate modules will cover specific ranges and types of particles. Some particles will be formed in-situ, and will require promotion by light or other radiation sources which are designed as Experiment Specific Modules. This technique of an interchangeable module will allow for development of special modules not already provided.

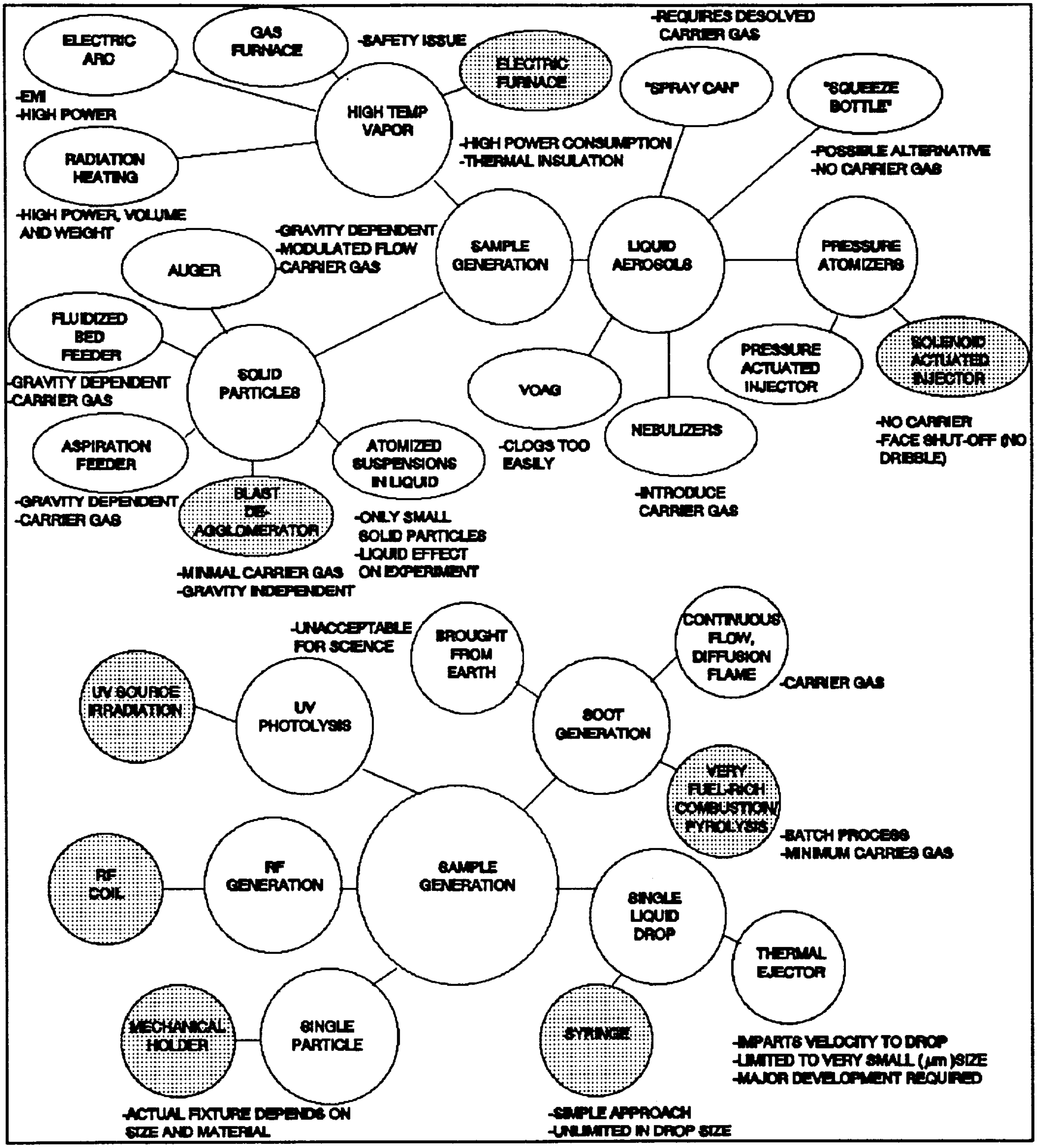


Figure 5 - Selected Sample Generation Methods (shaded).

The elements that need to be considered while designing are shown pictorially in Figure 6. These elements have different values for each generator type and each experiment.

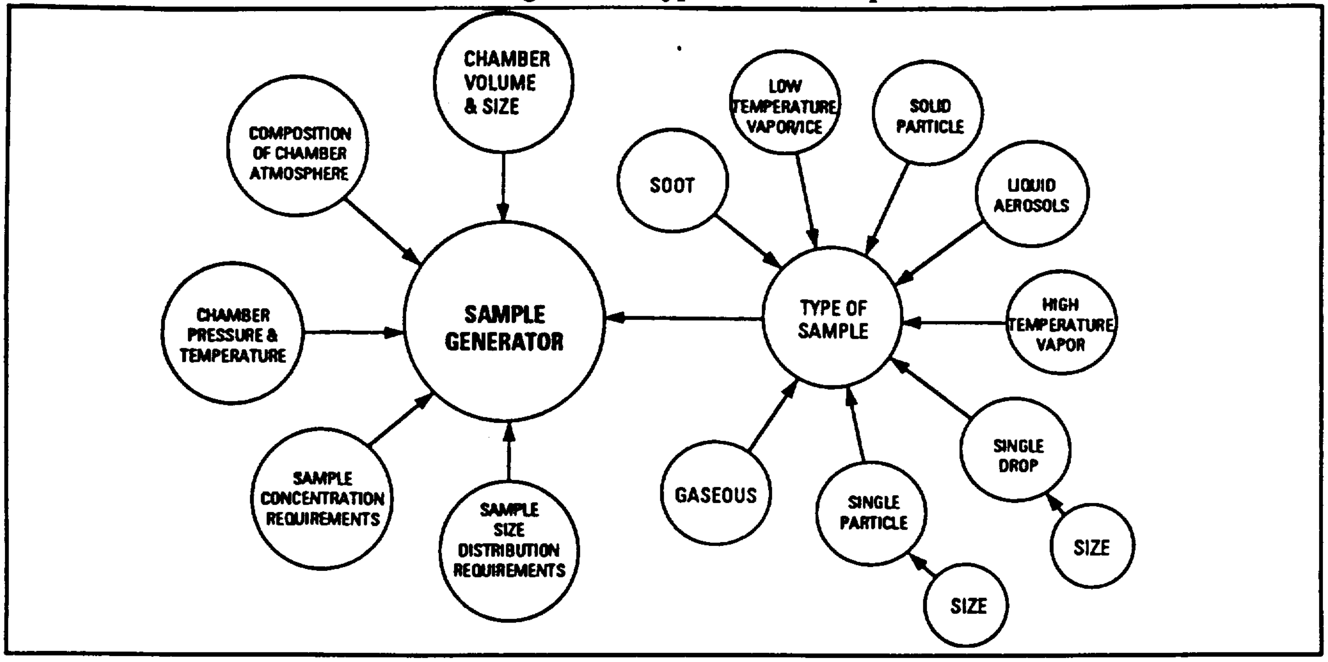


Figure 6 - Important Elements of the Sample Generator Design.

As part of this subsystem, two storage drawers are provided that mate with a standard Space Shuttle middeck locker. These drawers are used to store generators and collected samples on SSF, as well as transport hardware between the facility and earth. Two drawers are required to allow preparation and transport of one set of hardware from earth, while the second drawer is on the facility being used for storage.

3.4 Diagnostics Subsystem

Extensive diagnostics are required on the GGSF to monitor and record particle actions and interactions, as well as of the environment surrounding the particle. The diagnostics are classified into **on-line** and **off-line**, to distinguish between those used to monitor processes while they occur, and those used to investigate sample particles collected and evaluated later. Volume I, section 4.3 discussed the need for the detailed requirements for diagnosing particles and environments.

Most of the **on-line** sample diagnostics are optical, and therefore don't contact the particles, minimizing any affects on the experiment. Optical access is through the windows provided on the test chambers. Other diagnostics are used to measure temperature, pressure, humidity, and gas composition. These are connected to the chamber through interface ports. During the selection and design of these instruments, several common issues must be considered.

- Diagnostics mounted within this facility will need to meet all of the requirements for a manned space mission that were identified in the system requirements of section 3.1 in this document. These requirements include launch environment survival, offgassing and flammability requirements, and safe operation.

- The size of the instrument is a concern, as standard diagnostic units are very large and bulky relative to the size of the GGSF.

- The power available to operate the diagnostics will be limited, as most of the power will be directed to the chamber for temperature control.

- Many light sources and sensors depend on convective cooling, which is not naturally available on SSF as it is on earth. Many conventional devices will require modifications for conductive or forced-air cooling of electronics or other internal components that dissipate power.

It is also possible to mount smaller diagnostic components within the test chamber. This could include light sources such as solid state lasers, and sensors such as silicone detectors used for scatter measurements. Components mounted within the test chamber must be able to withstand or operate in the test environment. Depending on the test requirements, this can have varying impact on these components.

- Certain atmospheres at low pressures can result in reduced ionization voltages, causing arcing between electrical components and ground. This could require special insulation or devices.

- Low vacuum levels require near-zero offgassing and outgassing of components within the chamber, which precludes many standard devices.

- Many experiments require temperatures below -50C which is the lower survival or operational range of many electronic devices.

- Many experiments have temperatures above 80C which is a standard electronics upper operating or survival limit. In addition to experiment temperature requirements, the decontamination scenario between experiments can include heating the chambers to 200C or higher.

- There are limitations on power usage and component cooling as previously discussed.

Additional diagnostics require removal of the sample from the test chamber for close-up or other unique analysis. Off-line diagnostics will be used for those unique analysis requirements. The off-line diagnostics are available from different sources.

- GGSF-unique tools - These must meet the size, power, cooling, and safety requirements previously mentioned;
- SSF-provided LSE - These tools, including gloveboxes, microscopes, etc., are shared with other SSF experiments and functions;
- Earth-based diagnostics - The samples can be removed from SSF and returned to earth.

3.5 Sample Retrieval and Storage Subsystem

Some experiments require removal of the sample from the experiment chamber for the purpose of off-line diagnostics, or return to earth. Sample retrieval and storage methods will consist of a variety of methods, depending on particle size, the quantity of the particles to be recovered, the fragility of the particles, the storage temperature requirements. Definitive requirements for this purpose remain to be defined before a design can be developed for this subsystem.

3.6 Gas Handling Subsystems

The science requirements include the need for a variety of gas mixtures in the test chamber. These were discussed in Volume I, section 4.5. The types of gases required by each experiment is indicated in Table 7. This Table also indicates the amount of products required by the combination of all the currently "suggested" experiments, based on an average 10^5 cc test chamber volume.

The total quantity of gas required is too much to store on-line within the facility. Some solutions to this issue include:

- carry less tankage, and periodically replace depleted gases;
- use SSF avionics air and SSF-provided nitrogen;
- reduce the test chamber volume;
- reduce the number of repetitions of experiment.

The first option was selected as the most desirable and flexible option for the GGSF application.

Table 7 - Consumable Products Required by Experiments.

Does not include sample materials (aerosol, solids, etc.).

Exp. #	Air	N_2	H_2	O_2	H_2O	CO_2	CO	NH_3	CH_4	He	Ar	Xe	Others	Composition Control ± %
1			Y		Y	Y		Y	Y	Y				NS
2		Y	Y		Y									NC
3	Y												cetyl alc.	±0.01%
4					Y	Y		Y	Y					NS
5	Y				Y	Y							SO_2/ H_2SO_4	5-10%
6	Y				Y								fuel	NC
7		Y				Y		Y	Y	Y	Y		S,P	<10%
8	Y				Y					Y	Y			1%
9		Y							Y					3%
10														NS
11		Y			Y	Y								5%
12	Y				Y									2%
13				Y		Y	Y							0.5%
14		Y	Y						Y					10%
15													Metal-Bearing Gases	5%
16			Y	Y	Y	Y	Y	Y	Y		Y	Y	SiO, Fe, Mg	5%
17														NA
18	Y													NC
19	Y				Y									NC
20	Y				Y									NC
21	Y												C_2H_2	1%
NA-Not Applicable; NC - Not Critical; NS - Not Specified; y - Yes														
Total quantity of gas required (m^3 at STP)														
All	37	23	19	.10	NS	4.0	.01	1.3	1.3	12	16	NS	NS	

The gas storage can be in the form of pure gases, pre-mixed gases or some combination of the two. Table 8 shows the trades associated with this issue.

By storing pure gases and mixing them in-situ, the gas mixtures could be varied at will. This maintains a more flexible facility, and requires less individual tanks than providing all pre-mixed gases. This system is also more complex, in that metering, and probably monitoring, of the gas mixtures is necessary to obtain the desired test mixture of gases. A mixing enhancement method is required due to the lack of natural convection to assist mixing.

Carrying pre-mixed gases results in a less complex, but much more limiting system. Many bottles of pre-mixed gas would be necessary, but mixing, metering, and monitoring would not be required.

Combining the commonality of gas requirements indicated in Table 7 with the trade off results of Table 8, the selected method is a combination of the pure gases with some pre-mixed gases for specific experiment space applications.

Table 8 - Gas Storage trades.

	Approach	Pros	Cons
Premixed Bottles	Carry *n* pre-mixed gases in bottles: fill chamber directly with mixture	✓Simplest to implement ✓Avoid complex mixing procedures & metering ✓Shortens the timeline ✓Maximizes the utilization of stored gases ✓Eliminates mixing chamber (save weight, volume, plumbing)	✓Provides no flexibility in changing composition for subsequent testing
Mix in Experiment Chamber	Carry bottled pure gases; mix in chamber by metering partial pressures during the fill; must account for temperature variations during fill and for gas compressibility factor.	✓Provides flexibility in mixture composition ✓Eliminates mixing chamber (save weight, volume, plumbing)	✓Prolong the timeline since mixing is required for each test repeat ✓Complicates chamber design; need a fan ✓Requires humidity control in chamber ✓Timeline is long since mixing is done for each experiment repeat ✓No good repeatability in mixture preparation
Combination of A & B	Carry *n* pre-mixed gases in bottles plus a few bottles of pure gases; use pure gases to mix in chamber for composition corrections	✓Has the advantages of both A&B	✓Allows only minor composition changes
Use a Mixing Chamber	Carry only pure gases; prepare all mixtures in a mixing chamber; prepare mixtures for multiple refills; same procedure as in C.	✓Provides flexibility in mixture composition ✓Reduces experiment timeline ✓Assures uniform mixture for experiment repeats	✓Need a special tank(weight, volume, controls) ✓Under-utilized gas (either in bottles if mixing tank pressure is high, or in mixing chamber if it has large volume)

3.7 Waste Management Subsystem

A Waste Management Subsystem provides the ability to evacuate the test chamber, mixing chamber, and associated plumbing, for the purpose of decontamination of the systems in preparation of the next experiment. This assembly utilizes the SSF vacuum system for offloading the gases. Due to limitations of contamination allowed by the SSF vacuum system, scrubbing of the gases may be required in some cases. The allowed contaminants are described in SSP30000, and were in a state of flux when this document was prepared. The scrubbers are replaceable and will be changed out on a maintenance schedule.

Additionally, the Waste Management Assembly contains traps and filters that are used for sample collection and removal. The particles are removed from these units and studied with the off-line diagnostics, or returned to earth for further investigation.

Other criteria that lead to the design described in section 4.3.5 include:

- the safety requirements associated with pressurized systems;
- the need to replace gases either individually or as a rack of bottles;
- the requirement to be able to humidify the gas mixture;
- the ability to replace filters and scrubbers after they are expended;
- safely control rate and contaminants to meet effluent standards of the SSF vacuum systems.

3.8 Electronics Subsystem

This subsystem the provides control to facility subsystems, data acquisition and analysis, and housekeeping monitoring and reporting. Many of the requirements are discussed in Volume I, sections 4.10 and 4.12.

An important aspect of this subsystem is the flexibility it should include. It should be designed to accommodate the fast changing computer technology for the lifetime of the facility. The microprocessor evolution is expected to continue to double the CPU speed every 4 to 5 years as in the past decade. Additionally, various types of input/output modules may be required for different experiments; for instance, valve controllers, a frame grabber, thermocouple modules, preamplifiers and A/D and D/A units, heater drivers, etc. These modules should be adaptable to the facility in order to support facility upgrades or a capabilities increase.

3.9 Power Subsystem

The SSF provides its payloads with 120 Vdc. The GGSF Power Subsystem converts, conditions, distributes, and controls the power. The requirements for this subsystem are delineated in Volume I, section 4.9. The availability of power depends on the SSF and other payload requirements and the specific power timeline is TBD. The major power consumers will be the cryocooler, the electronics control system, the various hardware subsystems, and the turbomolecular pump. Due to the limitations of power and cooling availability, the power conditioning electronics should be as efficient as possible. Suppression of radiated and conducted electromagnetic interference is necessary to prevent affecting nearby equipment.

3.10 Position and Levitation Subsystem

The requirements for levitation and positioning are based on several different needs. Volume I, section 4.4 discussed these requirements in detail, some of which are summarized here.

- Performance of long duration experiments in vacuum requires levitation otherwise settling of the particles results due to the presence of low gravity. This effect was discussed in detail in Volume I, Appendix E, including settling times.
- Manipulation of particles may be needed to position particles, or maintain their position, in the view of the diagnostics field for certain experiments.
- There is a need to maneuver particles to facilitate collisions between them for some experiments.

The positioning and levitation requirements are major design drivers, in that these systems are complex in both hardware and control. Some of the design criteria associated with these systems include:

- fit within the envelope of the chamber being utilized for the experiment;
- the controller must fit within the available facility volume and power;
- operate in a vacuum environment for those experiments requiring that environment;
- avoid radiating fields that disturb surrounding facilities and instruments, such as RF or sonic radiations;
- support particle clouds or multiple particles in suspension without affecting particle distribution or homogeneity, or damaging the particle's structure .

Some of these requirements have yet to be resolved in the laboratory and may require extensive R&D studies.

3.11 Structures Subsystem

This structures subsystem is the ISPR with appropriate modifications to package and mount the facility subsystems for transportation to SSF, and used as a unit to interface with SSF storage and operation. The design criteria for this subsystem are:

- fit into a standard SSF ISPR, and meet the required mass and mass distribution for transportation to SSF;
- use the standard ISPR cover for shipping and launch, which provides the required ISPR stiffness and component containment in case of a failure resulting in a loose part;
- accommodate the GGSF subsystems;
- allow simple and quick exchange of test chambers;
- maintain alignment and positioning of the diagnostics through shipping and handling loads, and for different chambers when interchanged;
- allow access to and removal of filters, scrubbers, and gas bottles that are regularly maintained;
- provide for upgrading of electronics and diagnostics as technology progresses;
- provide shielding and insulations that protects the operator from hot and cold surfaces, stray radiation, or loose parts.

4 PHASE A CONCEPTUAL DESIGN

This section describes the GGSF conceptual design resulting from this Phase A Study. The design options, criteria, and elements described in Section 3 are culminated in to this design. The majority of the effort of developing and defining this conceptual design was concentrated on the system level integration, the gas handling subsystem, the test chambers, and a couple of the particle generators. The particle generator design is supported by an on-going breadboard development of a solid particle generator, which will be reported separately as an additional NASA Contractor Report.

A lesser effort was expended on the particle diagnostics. A survey of many commercially available technologies in particle counting and sizing that may be adapted was conducted. There is also much happening in the science community concerning this field that will be supportive of the next phases of the GGSF development.

No design effort was expended on particle manipulation or levitation. The experiments defined to date have requirements that are unique, and require further research in order to adequately define the design requirements. Some of these manipulation functions are experiment specific, and should be developed by the investigator as part of an experiment. Additionally, levitation is in a development stage, and should be considered as a technology development effort with regards to incorporation into the GGSF.

Though they are important, specific system interfaces such as fire detection and control, vacuum, nitrogen, avionics air, and cooling water were not addressed in detail due to the fluctuation in the SSF interface requirements. The incorporation and use of these resources should be straight forward once the definition becomes available.

4.1 The GGSF Phase A System Design Requirements

The concept for the GGSF system is based on a core facility that is transported to SSF as a package using a SSF International Standard Payload Rack (ISPR) and cover. The system design is a series of subsystems that satisfy system level design requirements. The system is designed around an experiment chamber with environmental control (pressure, temperature, humidity, and gas mixture), particle generators, and on-line diagnostics (environmental monitoring, optical characteristics, and imaging). Other support functions include a computer for experiencing operation control and data analysis, and off-line diagnostics capabilities (particle capture, removal, and analysis).

The GGSF system interfaces with SSF using an ISPR which allows utilization of required SSF resources such as air and water for cooling, nitrogen for purging, vacuum system for achieving low experiment chamber pressures, power, and data transfer capabilities. These details are discussed in section 4.1.2.

4.1.1 GGSF System Design - Table 2 described the different GGSF subsystems and their purposes. These GGSF subsystems fits in a single SSF rack volume. Subsystems are integrated using an ISPR and other structural parts which make up the Structures Subsystem.

The experiments are performed in experiment chambers that are interchangeable. Different chambers can be designed to accommodate specific experiment requirements. As a basis, a core chamber is provided to fulfill the needs of many experiments, with special chambers designed to provide capability for each of these following areas, very high temperatures, very low temperatures, and hard vacuum. The chambers have ports for interfacing Experiment Specific Modules (ESM) used to generate or retrieval of particles, windows for optical diagnostics, connectors for power and signal, and inlets for gas handling. These port interfaces are common to each chamber to enhance the ability to change out devices.

ESM's can be used to generate, manipulate, or retrieve particles. The baseline includes particle generators for large and small liquids and solids, in both single particle and cloud form, as well as UV and RF sources. Other devices can be added to the facility at any time, as long as they utilize the standard port and electrical interfaces. A standard storage drawer is part of this subsystem for ESM and collected sample storage.

A Gas Handling Subsystem is used to provide 9 standard gases and 3 user pre-mixed gases. These gases can be passed to a Gas Mixing Subsystem, where a fan is used to promote mixing and allows humidification of the mixture. Figure 31 schematically represents this subsystem.

The Diagnostics Subsystem provides on-line environmental monitoring with pressure and temperature sensors, optical scattering and extinction measurements, and gas chromatography. Off-line diagnostics will use the Waste Management Subsystem for collection of particles, and allow removal of the particles for analysis. This subsystem operates in conjunction with the SSF vacuum systems.

GGSF experiment control, data acquisition, analysis, and power distribution are provided by the Electronics Subsystem. The basis of this subsystem is an experiment computer and support peripherals that can be upgraded as technology advances or facility capabilities are modified.

Facility power is provided by SSF to the Tertiary Power Distribution Assembly (TPDA), which is a standard SSF unit. The power is then transferred to the GGSF Power Distribution Unit where it's conditioned and distributed to other experiment subsystems. This unit serves to regulate voltage, control current, switch power to controller-indicated lines, breaker higher-than-normal current draws. This unit also isolates the effects of facility devices from each other and from the SSF power system, including conducted EMI and surges caused by starting and stopping of inductive devices.

Allocations for mass and power of the Core Facility components and assemblies, are delineated in Table 9.

Table 9 - System level allocations of mass properties and power consumption.

Subsystem or assembly	Weight(kg)	Peak/Ave Power(watts)	Comments
Core Chamber	36.4	6/3	Power is for heaters
Cryocooler	7.3	640/640	based on TRW flight design
RF Generator	0.5	120/120	
UV Generator	0.1	30/30	
CCD Camera	0.9	3/3	
Light Sources (mono & white)	5.9	80/50	
Gas Storage Assembly	42.3	30/0	solenoid valve power used for short term
Gas Chromatograph	0.5	5/2	based on flight units such as the VLBI
Gas Mixing Assembly	13.6	5/5	power is for mixing fan
Aerosol Generator	2.7	10/0	only used during dispensing
Solid Particle Generator	2.7	10/0	only used during dispensing
Crucible	1.4	40/40	electric furnace type
Cryocooler Power Unit	20.5	200/200	
Control Computer	29.6	10/10	
Power Conversion/Distribution	38.6	245/233	
Input & Display Monitors	7.3	20/20	LCD type
Diagnostics Electronics	2.7	10/10	
Valve & heater drivers	3.2	50/5	
Video & Data Recorder	4.5	30/30	
MDM 16	21.4	tbd	standard SSF hardware
TDPA	63.6	tbd	standard SSF hardware
Storage Locker	2.3	0	
Particle Sizer/counter	12.7	45/45	
Misc Structure & optics	46.4	0	
Misc. Cables	13.6	0	
Misc. Plumbing	20.5	0	
Total Mass	411	n/a	Mass Margin of 89 kg; total power not applicable since devices are used separately

4.1.2 GGSF System Interfaces - The GGSF is designed for use in the SSF U.S. Module. The installation is accommodated by the use of an ISPR, a standard Modulator/Demodulator Module (MDM) for interfacing data links, and a standard TPDA for interfacing to the station power. The GGSF will also tie into the SSF avionics, nitrogen supply, and vacuum system. The interfaces between the U.S. Module and the GGSF are summarized in Table 10. The table also shows which GGSF subsystems are the users of the specific utility supplied by the U.S. Module. Schematic interface drawings are shown in Figure 7 through Figure 10.

Table 10 - GGSF interfaces to SSF.

U.S. Module Utility per SSP30000	GGSF Interface & Distribution	GGSF Users Subsystem
Cooling water or Low temperature cooling water	Shut-off valve and manifold[1] controlled via the environmental control subsystem	Waste management, sample generator, diagnostics (possibly to cool high power lamp)
GN$_2$ (Integrated nitrogen supply)	Shut-off valve and manifold	Gas storage and mixing, chamber, sample generation
VRS/VES	Shut-off valve at outlet of waste management subsystem	Chamber, GC, gas storage and mixing all through the waste management subsystem.
Electrical Power	Primary and secondary power conversion and distribution subsystem	Sample generation, chamber heaters and cryocooler, diagnostics, positioning and levitation, gas storage and mixing, waste management, sample collection and storage, command & data handling, environmental control
P/L network, FDDI, MIL-STD-1553	Direct interface to C&DH	Sample generation, chamber heaters and cryocooler, diagnostics, positioning and levitation, gas storage and mixing, waste management, sample collection and storage, command & data handling, environmental control
Time distribution	Direct interface to C&DH	N/A
Video	Direct interface to C&DH	Diagnostics
Avionics air	Shut-off valve and manifold controlled via the environmental control subsystem	Electrical power conversion and distribution, C&DH, sample generators,
Fire suppressant CO$_2$ line	Distribution manifold TBD	TBD

[1] The use of the cooling versus low temperature water cooling loops is TBD.

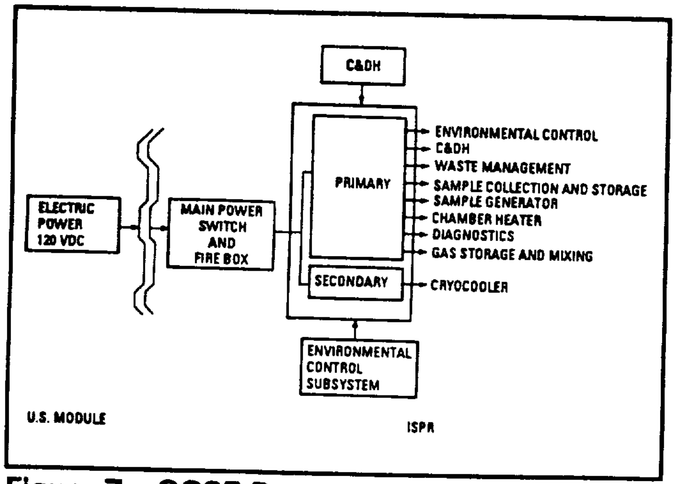


Figure 7 - GGSF Power interface.

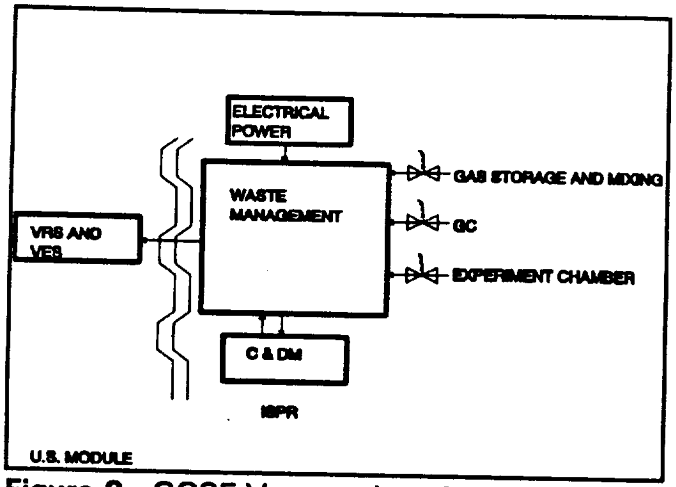


Figure 9 - GGSF Vacuum interfaces with SSF.

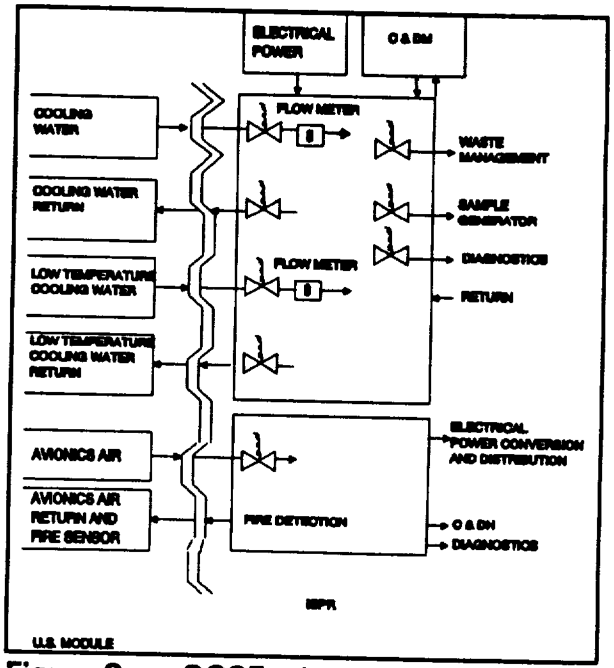


Figure 8 - GGSF thermal control and avionics interfaces to SSF.

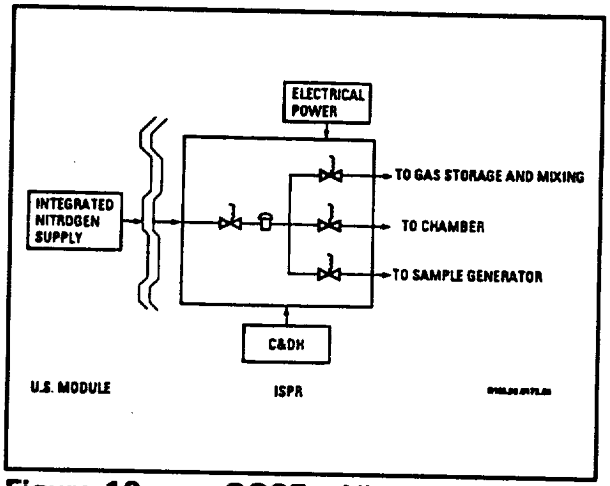


Figure 10 - GGSF Nitrogen Supply interface to SSF.

4.2 Design Drivers

Some major design constraints and drivers result from the requirements derived in Volume I and section 3 of this volume. Some of these are very difficult to accommodate in a reasonable design. Examples of these design drivers include:

- 4K temperature - This is accomplished either through cryogenics, which are restricted on SSF, or large refrigeration units which exceed the power and volume constraints of the facility.
- hard vacuum of 10^{-10} bar - SSF provides vacuum on the order of 10^{-6} bar. A turbo-molecular or other type vacuum pump is required to support the requirement, but compatibility with drifting particles will be an issue.
- chamber cleanliness - Experiments require a contamination free chamber at the initialization of the experiment. This will require cleaning between experiments resulting in need to develop a totally automated cleaning process for the man-tended phase of the mission. Human interaction may be utilized for the later manned phase of the mission. The issue of chamber cleanliness will significantly drive the chamber design depending on the types of contamination that will be present. For example, large particles may be lifted into suspension, then purged, condensates might be baked off, but small particles that stick to the wall may require chamber disassembly. Scheduling of experiments may help to solve this issue by allowing contamination of previous experiments that don't affect the current experiment.
- transportation weight - The limitations on the allowable mass for transport to SSF could drive some components to light weight designs. This can limit the use of existing component/subsystem designs or proven technologies in certain cases. Weight constraints have not been identified for the SSF.
- rack size - The volume of the Mature Facility is driven by the requirement to fit within one ISPR's volume. This requirement drives subsystems and components to miniaturization. This limits utilization of existing hardware and, in some cases, technologies. Additionally, it can burden packaging when interchangability is a requirement.
- levitation of clouds - No method has been identified for accomplishing this. The requirement is to keep a cloud of particles suspended in a vacuum without disturbing the particles and cloud homogeneity. Volume I of this report discussed the particle velocity as a function of pressure, particle size, and gravity, indicating that settling can happen very quickly in low pressures. Methods of suspension have non-uniform characteristics which will disturb the homogeneity and relative locations of the particles.

4.3 Subsystems and Components

This section discusses the designs of the subsystems that make up the GGSF. These subsystems are composed of assemblies and components that provide a given function, but may be spread throughout the facility, or may have replaceable and interchangeable parts on earth.

4.3.1 Chamber Subsystem - Based on the experiment requirements and the design constraints and drivers, the subsystem includes four different chambers to meet all the requirements. A fifth chamber that is dedicated to room temperature experiments and has no thermal control may be added as a low-cost addition to the subsystem.

4.3.1.1 General Design Approach: The chambers share many of the same considerations and requirements in their design. The four primary chambers will require temperature control, resulting in a design that is thermally stable and isolated. They will all have an internal-to-external pressure difference capability, and will require the integrity associated with pressure vessels. They will all have access ports for instrumentation, cleaning, and particle retrieval & generation that require sealing.

4.3.1.1.1 Thermal Design. The design of the chambers is highly dependant on thermal requirements. Chambers operating at very high or low temperatures must be designed to minimize heat transfer in order to keep power consumption within facility requirements, as well as protect surrounding instruments and nearby personnel. Chambers 1, 2, 3, and 4 include typical thermal control features.

- The chambers 1-4 have two pressure barrier walls with vacuum between them to minimize conductive thermal loads (see Appendix B, Volume I)
- Radiation shielding is provided between the walls to reduce radiative heat loads
- Electrical feed-throughs for power and sensor signals are thermally insulated
- Heaters are built in around the inner wall to heat the chambers to 400 K and for bake out (1,200 K for chamber 4)
- The cryocooler is attached to the inner wall (no cooler for chamber 4).
- Chamber 5 is a single-walled chamber with no thermal control capabilities.

4.3.1.1.2 Materials. Chamber materials are selected to help fulfill the thermal control requirements, provide structural integrity, and control contamination. Consideration for material selection include weight, mechanical and physical properties over the applicable temperature range, and catalytic resistance with respect to the experiment materials. An inner chamber provides high thermal conductivity to minimize thermal gradients and cool-down time. For the cooled chambers

(1, 2, 3) aluminum is tentatively selected. Copper coatings may be applied to improve thermal conductivity. For the high temperature chamber, the inner wall material could be Inconel, possibly with a plated ceramic liner. The outer wall material could be corrosion resistant steel or titanium, providing thermal insulting properties and integrity at temperature extremes.

4.3.1.1.3 Cleanliness. A critical concern is the cleanliness of the walls and windows within the experiment chamber. The residual materials from a previous experiment in the same chamber could result in corrupted data for the current experiment. Some potential chamber cleaning approaches recommended for future GGSF studies include:

- boiling off condensables from chamber walls and venting out through the SSF vacuum system;
- purging suspended particles from the chamber with GN_2 and vent to the SSF vacuum system, several times if required;
- treat windows with anti-static coatings including thin layers of conductive metals coating;
- schedule experiments in a sequence that reduces the impact of contamination;
- remove chamber and install a replacement chamber for a new sequence of experiments;
- return chamber to earth for clean up and assembly.

Other possible approaches that were considered are more complex or could result in hazardous situations. These include:

- use of the glove box and workbench on SSF to open, clean up and reassemble chamber. Disassembly of the chamber for clean up on board the SSF is not recommended due to the inherent difficulty in verifying the integrity of the chamber seals upon re-assembly. This could result in vacuum leakage or cabin contamination from chamber gases or particles.

- installation of a window purge subsystem. This would only work in a small isolated area, and would otherwise require manipulation in order to broaden the coverage by such a device.

4.3.1.1.4 Joints and ports. Access and interface ports are provided in the chamber for the installation of particle generators, instrumentation, and plumbing fittings, as well as viewing for optical data acquisition. A summary of the ports and windows availability for the chambers is shown in Table 11. Some general design features are: (a) the camera and the illumination ports are flush mounted to the inner chamber to maximize the field of view (FOV), (b) the ports contain ceramic sections to reduce conductive heat loads between the inner and outer walls, (c) a single port is utilized for gas inlet, vent, sample collection, pressure sensor, and gas chromatograph sample line, as shown in Figure 11, (d) windows not required for certain experiments are blanked to reduce

Table 11 - Summary of chamber ports

Key: ◆ = incorporated, ▣ = not incorporated in design

Port No.	Function	Designation	Chamber No.				
			1	2	3	4	5
1	Large removable lid (inner & outer shells)	-	◆	◆	◆	◆	◆
2	Internal mounts (detector ring, other in-chamber assemblies)	-	◆	◆	◆	◆	◆
3	High vacuum pump interface	-	▣	▣	◆	▣	▣
4	Sample generator 1 port	A	◆	◆	◆	◆	◆
5	Sample generator 2 port	B	◆	◆	◆	◆	◆
6	CCD camera 1 window	C	◆	◆	▣	◆	◆
7	CCD camera 2 window	D	◆	◆	▣	◆	◆
8	Camera 1 front illumination window	E	◆	◆	▣	◆	◆
9	Camera 2 back Illumination window	F	◆	◆	▣	◆	◆
10	Detector port window (in-line with radiation window)	G	◆	◆	◆	◆	◆
11	Collimated radiation source window	H	◆	◆	◆	◆	◆
12	Power electrical feed-through	I	◆	◆	◆	◆	◆
13	Sensor output electrical feed-through	J	◆	◆	◆	◆	◆
14	Vent/gas fill, etc. line connect	K	◆	◆	◆	◆	◆
15	Cryocooler interface	L	◆	◆	◆	▣	▣
16	Sample generator 3 port	M	▣	▣	◆	▣	▣

Chamber 1 - core; 2 - low temp., 3 - high vacuum, 4 - high temp., 5 - ambient.

radiative heat loads, (e) all port positions are common to all chambers, to assure interfaces with diagnostics and sample generation hardware, and (f) all ports for similar functions have a common interface on all chambers.

Several chamber joints can be opened to provide access for cleaning, installation of the particle generators, or exchange of damaged hardware (windows, detectors, etc.). Sealing of these joints is critical to maintaining an experiment isolation environment from the cabin (e.g., internal chamber pressures above or below cabin pressure). Several seals selected for the chamber design are listed in Table 12.

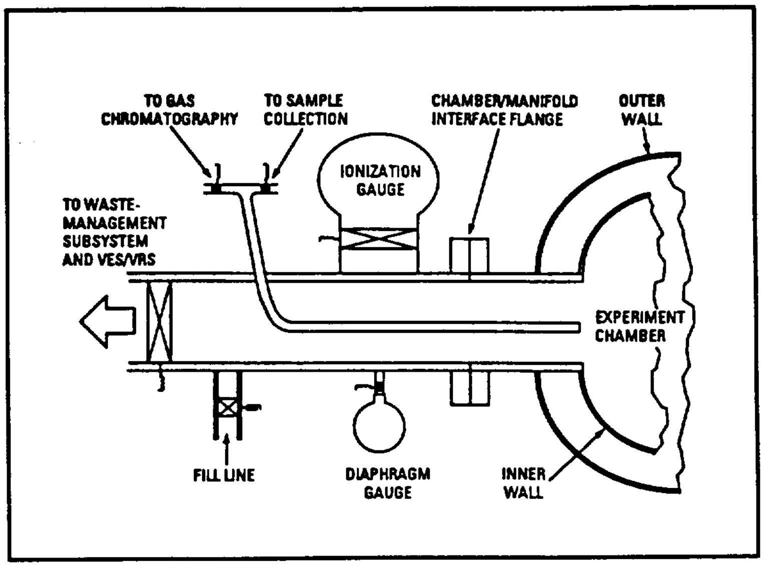


Figure 11 - Gas handling interface to experiment chambers.

Table 12 - Seal types and possible locations.

Elastomeric: Outer wall flanges	220 - 500 K 10^{-6} - 700 bars	Most resilient type seal; easiest to install
Spring energized Teflon: Cryocooler interface and inner wall flanges	20 - 500 K 10^{-9} - TBD bars	Requires lower clamping load than plated metal o-ring; thinner flanges
Plated metal O-ring: High temperature chamber flanges	4 - 1366 K 10^{-14} - 68,000 Bars	Require high clamping load, broadest temperature range, most difficult to install
Notes: Each chamber seal must be verified for integrity. On board testing is undesirable due to potential environmental contamination, therefore, the number of seals to be broken in orbit should be limited. Possible installation difficulties with plated metal o-rings preclude replacement in-orbit.		

4.3.1.2 Core Chamber: The core chamber is the primary chamber, designed for compatibility with most of the experiments. This chamber is the first to be fabricated and deployed in the Core Facility. The volume of the core chamber has been maximized. However, this puts limitations on cooling and heating capabilities due to the associated power consumption. The core chamber design is shown in Figure 12.

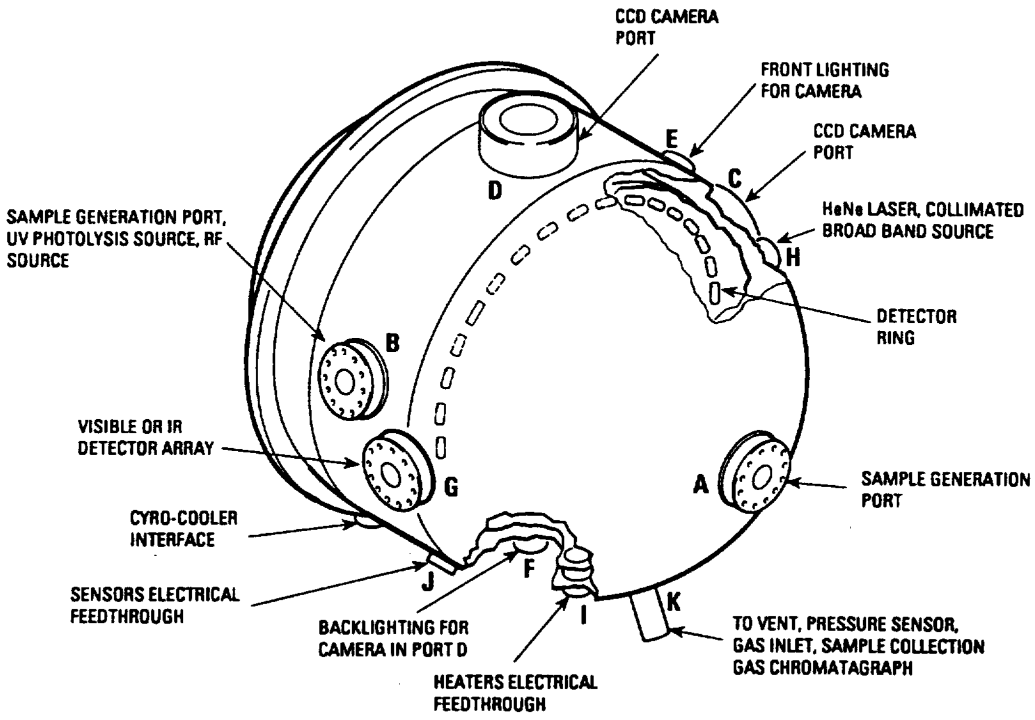


Figure 12 - Core experiment chamber.

The chamber has two walls with a vacuum jacket between them for thermal insulation. The vacuum is provided by the SSF vacuum system. Both the inner and outer walls are sealed with full diameter flanges that can be separated for access to instrumentation and samples. The aluminum inner wall is configured for temperature control, with flexible heaters bonded to the exterior, and a cryocooler attached through a vacuum sealed fitting. Resistance Thermal Detectors (RTD's) are located in several positions to provide wall temperature and gradient information. The external wall is corrosion resistant steel (CRES), and provides thermal resistance to the external environment as well as the means to meet pressure vessel safety requirements. An RTD is located on this wall and monitored for safety, to assure that no hazardous conditions result due to excessive temperatures (hot or cold).

The chamber windows are installed into thermally isolated fittings to minimize heat leakage. The window system will be double glazed (two layers of glass) with a moderate vacuum between the layers. This is necessary to avoid icing of the window external surface, or overheating of instruments mounted against the window. The windows are removable for cleaning and replacement, with elastomeric seals. The windows will likely have coatings with anti-reflective and anti-static properties. These coatings can be optimized for wavelength of the data acquisition instrument used in that window, and the thermal and chemical environments it is exposed to.

The core chamber is outfitted with 2 standard sample generator ports. One port is located at an hemispherical end, permitting the maximum possible distance to the opposite wall. This scenario allows stopping distance for small particles that are dispersed with a velocity. The second port is located in the center of the cylindrical section to provide maximum access to the center of the chamber should manipulation or other particle interfacing be required.

Table 13 indicates the compatibility of this chamber with the GGSF experiments in terms of fulfilling temperature, pressure and volume requirements. The interfaces for this chamber vary with the experiment to be performed. Table 14 indicates the usage of the chamber interfaces as they apply to the experiment that the chamber is used for.

Table 13 - Core Chamber Compatibility Matrix

◆ = chamber meets experiment requirements, ◘ = experiment requirements not satisfied by this chamber
partial compatibility with experiments is indicated where applicable

Experiment No.	Temperature in Range 150 to 400 K	Pressure in Range 10^{-6} to 1 bar	Volume less than 67,000 cm^3	Experiment/ Chamber Compatibility
1	◆ (partial)	◆	◆	◆ (partial)
2	◆	◆	◆	◆
3	◆	◆	◆	◆
4	◆	◆	◆	◆
5	◆	◆	◆	◆
6	◆	◆	◘ (too large)	◘
7	◆ (partial)	◆ (partial)	◆	◆ (partial)
8	◆	◆	◘ (too large)	◘
9	◆	◆	◆	◆
10	TBD	TBD	TBD	TBD
11	◆	◆	◆	◆
12	◆	◆	◆	◆
13	◆ (partial)	◆	◘ (too large)	◘
14	◆	◆	◆	◆
15	◆	◆	◆	◆
16	◆ (partial)	◆	◆	◆ (partial)
17	◆ (partial)	◆	◆	◘
18	◆	◆	◘ (too large)	◘
19	◆	◆	◘ (too small)[1]	◘
20	◆	◆	◘ (too small)[1]	◘
21	◆	◆	◆	◆

[1] Acceptable to investigator since larger chamber may not be available.

Table 14 - Core chamber interfaces as they apply to each experiment.

Port Port	Function Function	Experiment No. (◆ =incorporated)														
		1	2	3	4	5	7	9	10	11	12	14	16	19	20	21
A, B	Liquid aerosol generator									◆				◆	◆	
A, B	Solid particle dispenser	◆		◆		◆										
A, B	High temperature vapor generator								◆				◆			
A, B	Soot generator			◆												◆
A, B	*In situ* generator (UV or RF source)						◆	◆		◆		◆	?			
A, B	Single drop or particle generator		◆								◆					
B	Particle/droplet positioning	◆	◆								◆					
C,D, E,F	CCD cameras & lighting	◆	◆				◆					◆	◆			
G	Transmission/extinction detector (IR)					◆										
G	Transmission/extinction detector (VIS)			◆				◆	◆			◆		◆	◆	◆
H	Filtered broadband radiation source		◆			◆	◆	◆	◆					◆	◆	
H	HeNe laser			◆			◆	◆	◆			◆	◆			◆
I	Heater	◆	◆	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
J	In-chamber diagnostics (detector ring)						◆	◆	◆		◆	◆	◆	◆		◆
J	Temperature sensor(s)	◆	◆	◆		◆	◆			◆	◆	◆	◆	◆	◆	◆
K	Gas chromatograph			◆										◆	◆	
K	Sample collection or off-line diagnostics						◆	◆		◆	◆	◆	◆			
K	Pressure sensor(s)	◆	◆	◆		◆	◆	◆				◆	◆	◆	◆	◆
K	Gas fill/vent															
L	Cryocooler	◆	◆	◆		◆	◆			◆	◆	◆	◆	◆	?	

4.3.1.3 Low-Temperature Chamber: The low-temperature chamber design is similar to that of the core chamber, with the primary difference being a reduced volume. The reduced size (and hence internal volume) of this chamber allows much lower wall temperatures to be achieved within the power requirements of the facility, by accommodating lower surface areas and higher insulation values. The heating capability for this chamber is limited to 400K, which supports cleaning requirements for boiling condensates off the walls. A temperature sensor is included on the exterior surface of the inner chamber wall to monitor the wall temperature. More may be required if gradients are identified as a problem during thermal analysis of the chamber. However, the number of sensors should be minimized since each additional sensor represents increased heat leakage, increasing the lowest operating temperature of this chamber. The chamber size limits the experiment compatibility, as indicated in Table 15. The chamber interfaces, and how they are used for each experiment, are indicated in Table 16.

Table 15 - Low-temperature chamber compatibility with experiments.

◆ = chamber meets experiment requirements, ▣ = experiment requirements not satisfied by this chamber
partial compatibility with experiments is indicated where applicable

Experiment No.	Temperature in Range 40 to 400 K	Pressure in Range 10^{-6} to 3 bar	Volume less than 4,200 cm^3	Experiment/ Chamber Compatibility
1	◆ (partial)	◆	◆	◆ (partial)
2	◆	◆	◆	◆
3	◆	◆	▣ (too small)	▣
4	◆[1]	◆	◆	◆
5	◆	◆	◆	◆
6	◆	◆	◆	◆
7	◆[1]	◆[2]	◆	◆
8	◆	◆	◆	◆
9	◆	◆	◆	◆
10	TBD	TBD	TBD	TBD
11	◆	◆	▣ (too small)	▣
12	◆	◆	◆	◆
13	◆[1]	◆	◆	◆
14	◆	◆	◆	◆
15	▣	◆	▣ (too small)	▣
16	◆[1](partial)	◆	◆	◆ (partial)
17	◆ (partial)	▣	◆	▣
18	◆	◆	◆[3]	◆
19	◆		▣ (too small)	▣
20	◆	◆	▣ (too small)	▣
21	◆	◆	▣ (too small)	▣

[1] $T < 150$ K required. [2] $P = 3$ bars required. [3] Volume 125 to 3375 cm^3 required.

Table 16 - Low-temperature chamber interfaces as they apply to each experiment.

Port	Function	Experiment No.												
		1	2	4	5	6	7	8	9	12	13	14	16	18
A or B	Liquid aerosol generator													
A or B	Solid particle dispenser	◆			◆									
A or B	High temperature vapor generator												◆	
A or B	Soot generator													
A or B	*In situ* generator (UV or RF source)						◆		◆			◆	?	
A or B	Single drop or particle generator		◆							◆				
B	Particle/droplet positioning	◆	◆							◆				
C,D,E,F	CCD cameras & lighting	◆	◆				◆					◆	◆	
G	Transmission/extinction detector (IR)				◆									
G	Transmission/extinction detector (VIS)								◆			◆		
H	Filtered broadband radiation source		◆		◆		◆		◆					
H	HeNe laser						◆		◆			◆	◆	
I	Heater	◆	◆		◆		◆		◆	◆		◆	◆	
J	In-chamber diagnostics (detector ring)						◆		◆	◆		◆	◆	
J	Temperature sensor(s)	◆	◆		◆		◆			◆		◆	◆	
K	Gas chromatograph													
K	Sample collection or off-line diagnostics						◆		◆	◆		◆	◆	
K	Pressure sensor(s)	◆	◆		◆		◆		◆			◆	◆	
K	Gas fill/vent													
L	Cryocooler	◆	◆		◆		◆			◆		◆	◆	

4.3.1.4 High-Temperature Chamber: The high-temperature chamber is designed to satisfy experiments with temperature requirements between 400K and 1200K. The internal volume of this chamber is smaller than that of the core chamber to reduce heated surface area and allow for increased insulation. This keeps power requirements within the facility allocation and maintains the external surface temperature below injury levels or equipment damage levels. This chamber does not include the capability for cooling below cabin temperature. Cooling from high temperatures to ambient temperatures is accomplished by heat leakage to the facility structure over time, and can be facilitated by a nitrogen purge. The compatibility of this chamber with GGSF experiments is described in Table 17. The interfaces required by each experiment performed in this chamber are indicated in Table 18.

Table 17 - High-temperature chamber experiment compatibility.

◆ = chamber meets experiment requirements, ◘ = experiment requirements not satisfied by this chamber
partial compatibility with experiments is indicated where applicable

Experiment No.	Temperature in Range cabin to 1,200 K	Pressure in Range 10^{-4} to 1 bar	Volume less than 8,200 cm^3	Experiment/ Chamber Compatibility
1	◆ (partial)	◆	◆	◆ (partial)
2	◆ (partial)	◆	◆	◆ (partial)
3	◆ (partial)	◆	◘ (too small)	◘
4	◘ (too high)	◆	◆	◘
5	◆ (partial)	◆	◆	◆ (partial)
6	◆	◆	◘ (too large)	◘
7	◆ (partial)	◆ (partial)	◆	◆ (partial)
8	◘ (too high)	◆	◆	◘
9	◆	◆	◆	◆
10	TBD	TBD	TBD	TBD
11	◆ (partial)	◆	◘ (too small)	◘
12	◘ (too high)	◆	◆	◘
13	◆ (partial)	◆	◘ (too large)	◘
14	◆ (partial)	◆	◆	◆ (partial)
15	◆	◆	◆	◆
16	◆ (partial)	◆	◆	◆ (partial)
17	◆ (partial)	◘ (too high)	◆	◘
18	◆ (partial)	◆	◘ (too small)	◘
19	◆ (partial)	◆	◘ (too small)	◘
20	◆	◆	◘ (too small)	◘
21	◆	◆	◆	◆

Table 18 - High-temperature chamber interfaces as they apply to each experiment.

Port	Function	Experiment No.								
		1	2	5	7	9	14	15	16	21
A or B	Liquid aerosol generator									
A or B	Solid particle dispenser	◆		◆						
A or B	High temperature vapor generator								◆	
A or B	Soot generator									
A or B	*In situ* generator (UV or RF source)				◆	◆	◆		?	
A or B	Single drop or particle generator		◆							
B	Particle/droplet positioning	◆	◆							
C,D,E,F	CCD cameras & lighting	◆	◆		◆		◆		◆	
G	Transmission/extinction detector (IR)			◆						
G	Transmission/extinction detector (VIS)					◆	◆			
H	Filtered broadband radiation source		◆	◆	◆	◆				
H	HeNe laser				◆	◆	◆		◆	
I	Heater	◆	◆	◆	◆	◆	◆		◆	
J	In-chamber diagnostics (detector ring)				◆	◆	◆		◆	
J	Temperature sensor(s)	◆	◆	◆	◆		◆		◆	
K	Gas chromatograph									
K	Sample collection or off-line diagnostics				◆	◆	◆		◆	
K	Pressure sensor(s)	◆	◆	◆	◆	◆	◆		◆	
K	Gas fill/vent									
L	Cryocooler	◆	◆	◆	◆		◆		◆	

4.3.1.5 High-Vacuum Chamber: The high-vacuum chamber is provided to accommodate the experiments that require a hard vacuum of more than 10^{-6} bar. Currently, only experiment 17 falls into this category. The comparison of the chamber design with the experiment requirements is indicated in Table 19.

Special design considerations are necessary for hard vacuum. Material must be non-outgassing and inorganic. Special instrumentation is used to measure the vacuum level. Fittings, filters, and shields must not trap molecules, or the evacuation time can become excessive.

Table 19 - High-vacuum chamber compatibility.

	Temperature range (K)	Pressure range (bar)	Volume (cm^3)
Chamber Design	40-cabin	10^{-10} to 1	4,200
Experiment 17 requirement	10-300	10^{-10} to 10^{-8}	4,189

Note: temperature limited by cooler capacity and thermal loads.

The level of vacuum required in this chamber is well beyond that which is provided by SSF. The chamber will initially be evacuated with the SSF VRS, however a high vacuum pump is incorporated as an integral part of the high vacuum chamber in order to extend the vacuum to 10^{-10} bar regime. Figure 13 shows the configuration of this chamber with a pump. Turbo-molecular and getter-type pumps are candidates for this application. The use of a high vacuum pump requires a large chamber port to provide sufficiently high conductance, and the integrated concept provides the maximum opening possible. The issue of using the turbo-molecular pump in the presence of particles requires some investigation since particle impact on the turbine will cause damage or erosion. Some possible solutions to this issue include:

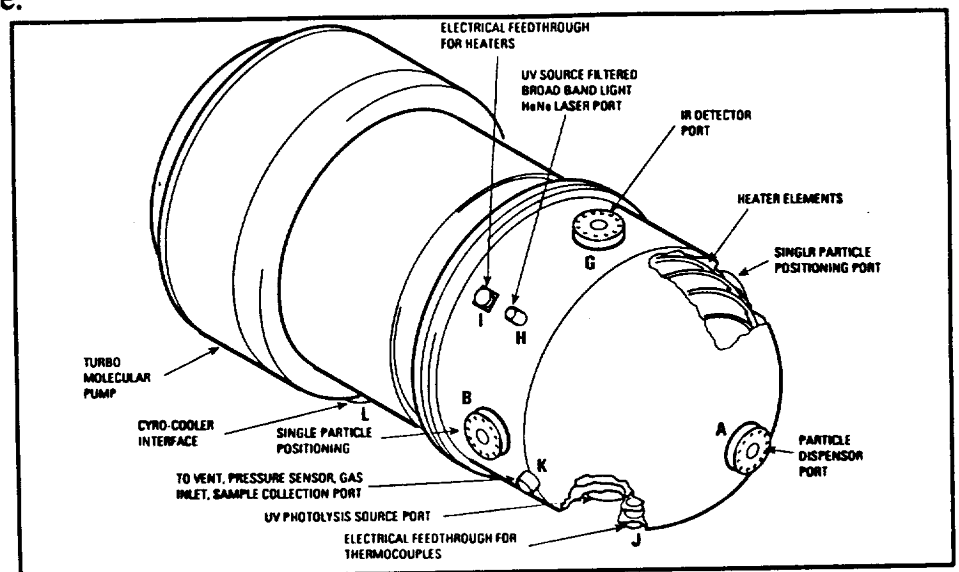


Figure 13 - High-vacuum chamber with integral turbo-molecular pump.

- pull a hard vacuum and shut down the pump prior to introducing particles. The maintenance of the required vacuum level may be difficult with the pump shut down.

- for small particles, allow the pump to operate during the experiment, risking some particle impact with the pump. This would probably require acoustically monitoring the pump for vibration resulting from fan erosion. Planned replacement of the pump will be required.

- for large particles, place a filter or shield between the pump and the chamber.

The interfaces that are required on the high vacuum chamber are indicated in Table 20.

Table 20 - High-vacuum chamber interfaces.

Port	Function	Experiment No.
		17
A or B	Liquid aerosol generator	◆
B	Particle/droplet positioning	◆
C,D,E,F	CCD cameras & lighting	◆
G	Transmission/extinction detector (IR)	
G	Transmission/extinction detector (VIS)	
H	Filtered broadband radiation source	
H	HeNe laser	
I	Heater	◆
J	In-chamber diagnostics (detector ring)	
J	Temperature sensor(s)	◆
K	Gas chromatograph	
K	Sample collection or off-line diagnostics	
K	Pressure sensor(s)	◆
K	Gas fill/vent	
L	Cryocooler	◆
Special	High vacuum pump	

4.3.1.6 Cryocooler: The cryocooler selection is based on the considerations of cooling capacity, power consumption, size, and weight. Commercially available cryocoolers can meet the requirements for the GGSF, with the exception of lifetime. Commercial and tactical cryocoolers are generally limited to about 2000 hours of operation.

The technology for cryocoolers is currently taking major steps towards extending life for use in space-based applications. TRW has a cooler rated at 0.25 watts of cooling capacity, with a 10 year design life, currently under life testing, and has exceeded 500 hours of testing at 60K, no load, at the writing of this document. Versions of this device have been built that produce the 15 watts required by GGSF, but have not yet been life tested or light-weighted for space applications. The heritage of this cooler is one that is operating nominally on the ISAMS instrument (the instrument has failed, but the cooler is still operating) since September, 1992. A 20K version is being built currently, which could be used on GGSF if the thermal losses are reduced or cooling is staged.

A commercial unit that meets the performance (not lifetime) requirements is manufactured by Cryodynamics. It is the largest available cooler in their line, with acceptable size and weight for the GGSF. Either air, or water cooled versions are available. The power unit weighs 20.5 kg (45 lb), requires 640 watts at 77 K and provides 15 watts of heat rejection.

The cooling capacity of the unit as a function of temperature and cool-down time (for the cold head only, no load) are given in Figure 14. Although the cooler can operate below 40 K, cooling the chamber further becomes a challenge due to the thermal load associated with the chamber wall losses, the windows, ports, and other interfaces.

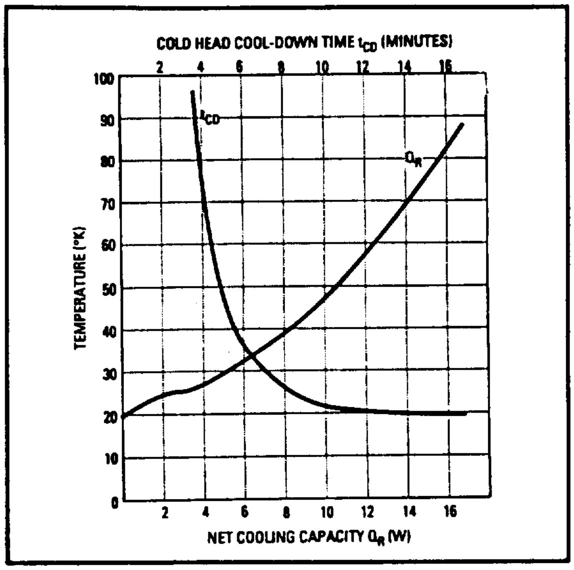


Figure 14 - Cryodynamics cooler performance.

A closed cycle helium refrigeration system is an alternative to the cryocooler discussed above. This type of device exhibits excellent performance but is heavy and has high power requirements. A reduction in the weight and power of this type of device may be possible under a technology development program. As a reference to the possible performance of a closed cycle helium refrigerator, the Balzers KelCoolã was selected. The KelCoolã refrigerator operates on a single or two stages with corresponding temperatures of 77 K and 6.5 K, respectively. The cooling power is up to 150 Watts for a single stage at 77K, and 20 Watts for a two stage system. This refrigerator consumes 4.3 kW of either 208-230 Vac (10/60 Hz), 380 Vac (30/60 Hz), or 460 Vac (30/60 Hz)electrical power, weighs 100 kg and uses about 9.46x10^{-2} liters/sec (1.5 gpm) of cooling water.

4.3.2 Sample Generation Subsystem - The Sample Generation Subsystem provides access for Experiment Specific Modules (ESM) or facility provided modules that are used to generate and manipulate particles. The various approaches reviewed for sample generators are shown schematically in Figure 5, and the selected candidate approaches are shaded.

An important requirement for most of the particle generators, is that the particles, once introduced into the test chamber, can be brought to rest in suspension. This problem has not been addressed in detail, however a discussion of it was given in Volume I, Appendix E. The concern is that particles are generally in motion when introduced into the chamber, and depending on particle density, size, and test chamber pressure, may impact and stick to the chamber wall or each other. Most desirable is a generator that introduces the particle(s) with no net motion, or in a condition that is acceptable to meet the experiment requirements. In other cases, the particles may require manipulation to stop or position them. This is considered experiment-specific, and is not addressed here.

4.3.2.1 Solid Particle Cloud Dispenser: Several particle dispersion and deagglomeration methods were considered. These are discussed in Table 21 and schematically shown in Figure 15.

The pros and cons for each technique are listed in the table, and the preferred approach is delineated in a heavy frame. The solid particle dispensing is accomplished with a blast deagglomerator that may be able to provide a cloud of sub-micron to 100 micron particles, either mono-dispersed or mixed together. The breadboard portion of this contract focused on this device, and is characterizing its effectiveness for the GGSF application. The blast deagglomerator is a technology used in commercial practice for separating particles.

Table 21 - Solid Particle Dispenser.

Concept	Description	Pros	Cons
Fluidized bed feeder (see Figure 15)	Particle bed is picked up by a gas stream creating a dilute suspension Carrier gas with suspended particles carried via a sample tube into experiment chamber	Simple technique and produces a relatively stable stream of solid particles in dilute suspension No reloading of powder required for repeat tests	Suspension is stabilized against gravity force, inappropriate for μ-g conditions No deagglomeration of particles carrier gas required Excess gas must be filtered and discharged. Amount of particles related to amount carrier gas
Auger feeder (see Figure 15)	Powder in packed bed is fed by an auger motion and conveyed by a carrier gas stream	Mechanically simple No reloading of powder required for repeat tests	No deagglomeration of particles Carrier gas required Gravity keeps powder in contact with auger Amount of particles related to amount carrier gas
Aspiration feeder (see Figure 15)	Powder placed in a thin layer on a surface Carrier gas in Venturi creates aspiration which picks up powder	Excellent control over feed rate of powder	Gravity required to keep powder on surface Carrier gas required No deagglomeration of particles Amount of particles related to amount carrier gas
Blast deagglomerator (see Figure 15)	Small amount of powder in a closed bed Rapid action valves opens and carrier gas suspends powder Powder fed through a shock wave for deagglomeration	Gravity independent Minimal amount of carrier gas Deagglomeration of particles Powder may be pre-loaded in bed Batch process	Least understood or tested technique, requires development tests to characterize performance Requires reloading powder for each test
Suspension atomizer	Particles form hydrosol in liquid Liquid atomized into small droplets Liquid evaporated leaving suspension of particles	No carrier gas required	May not work with all types of particles Difficult to deagglomerate particles in hydrosol (may require surfactants) Vapor of carrier liquid remain in system May introduce eroded particles from nozzle

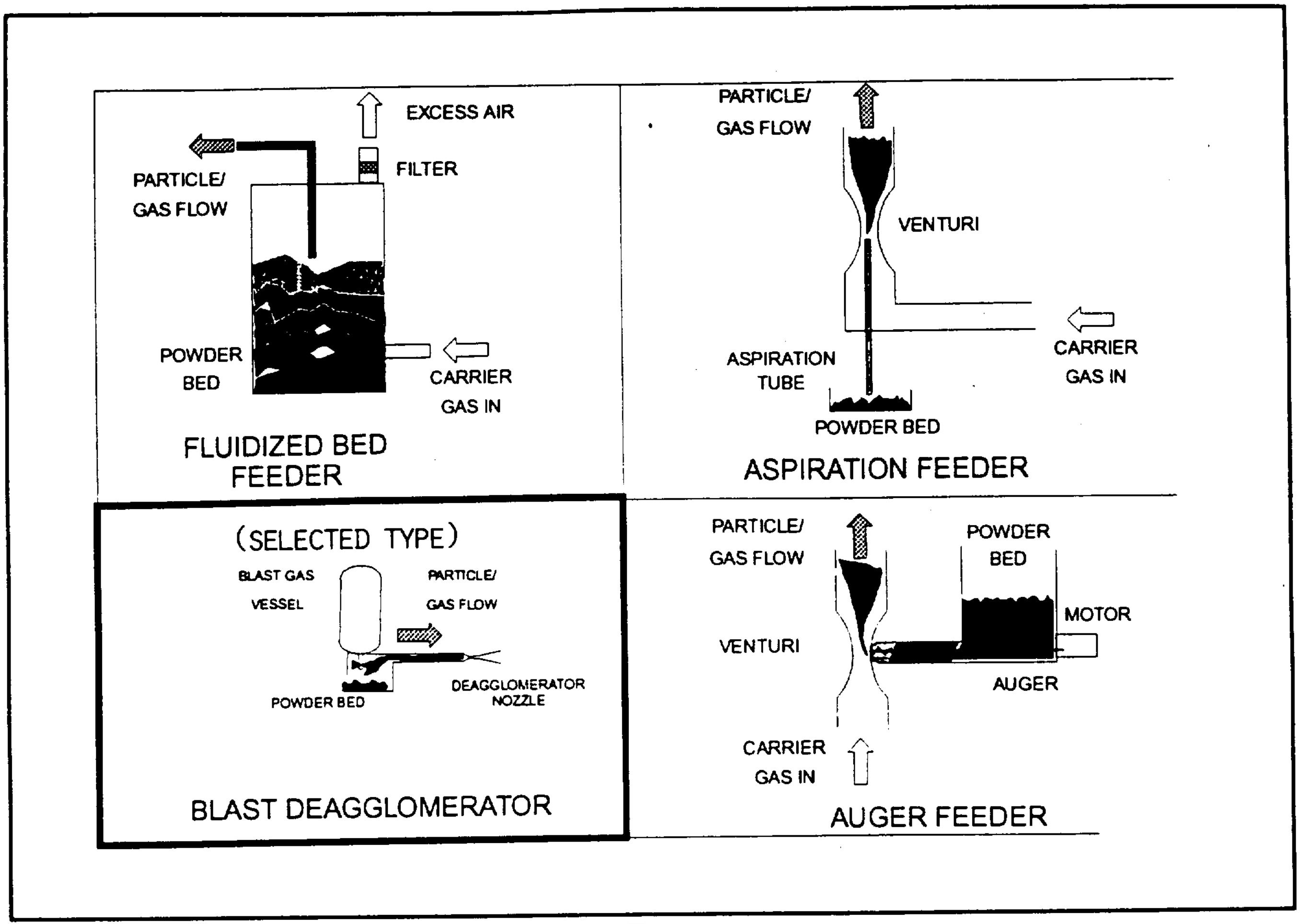


Figure 15 - Solid Particle Cloud Dispensers Types.

In this deagglomerator, the particle sample is carried through an aerodynamic nozzle, where shear forces and turbulence cause the particles to separate into single particles (as opposed to two or more particles stuck together). The particles are then injected into the test chamber where their motion must be stopped.

A downfall of the blast deagglomerator is the requirement for a carrier gas to move the particles through the aerodynamic shearing nozzle. This gas may prevent the use of this type of particle generator for experiments requiring low chamber pressure.

For larger solid particles, other techniques may work more effectively, some of which are discussed in section 4.3.2.3, but they are more conducive to generation of single particles than clouds of particles.

4.3.2.2 Liquid Aerosol Cloud Generator: Methods considered for aerosol generation are listed in Table 22. Because of the diverse set of requirements for the GGSF, more than one generator and technique may be required. The techniques are listed in the table in order of preference. The first technique is a pressure atomizer, due to the simplicity associated with this design. The last is the thermal ejector, which may require some development for this application. These techniques have commercial applications that can be used to derive a GGSF device that will dispense particles over a somewhat broad and random pattern. Figure 16 schematically indicates how some of these techniques work.

The effect of the spray formation technique on microbes has not been considered. The question whether a specific methodology such as an elevated pressure, or high frequency vibration may damage or harm the microbes must be assessed and tested.

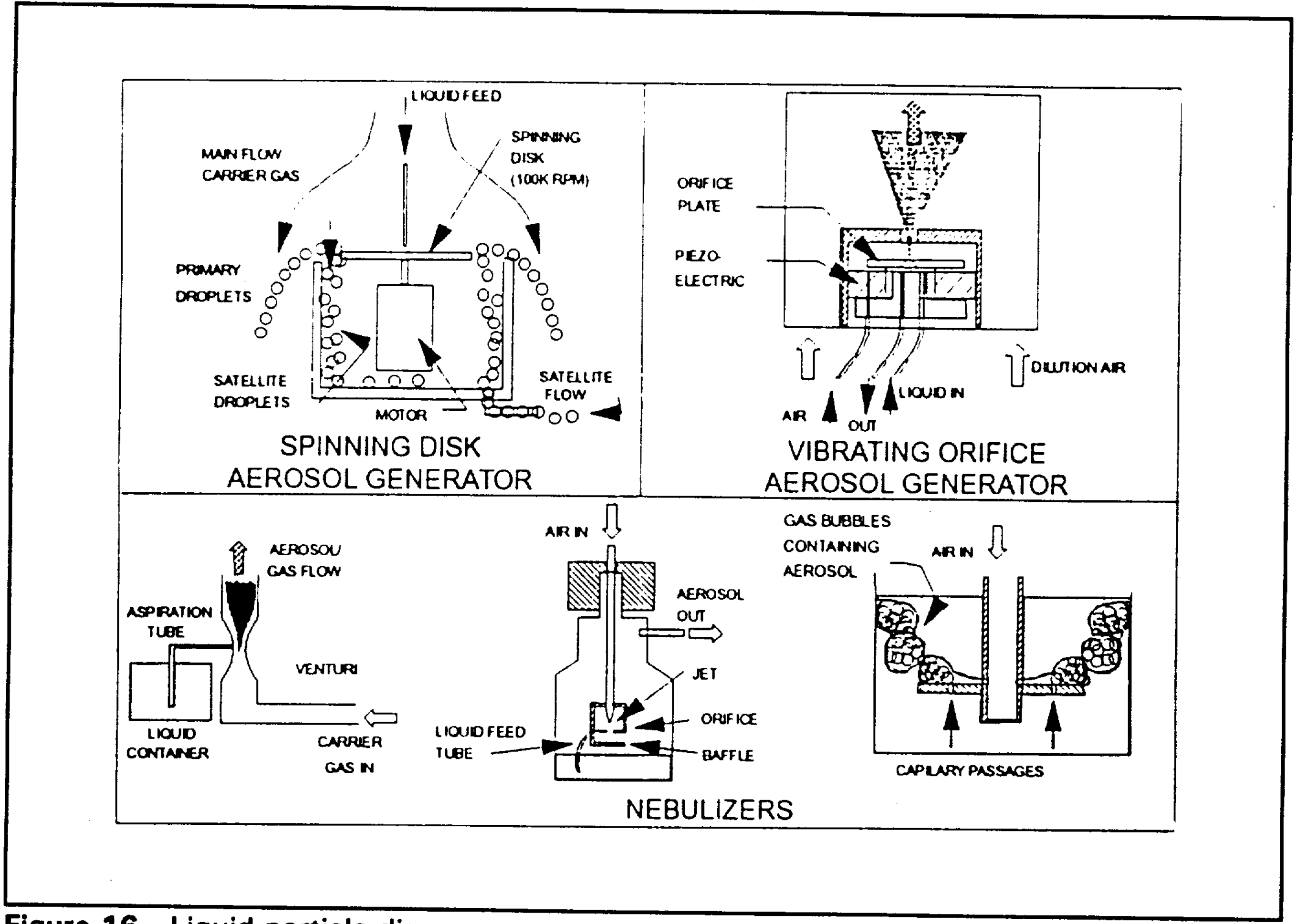


Figure 16 - Liquid particle dispensers.

Table 22 - Some Liquid Aerosol Dispenser Types.

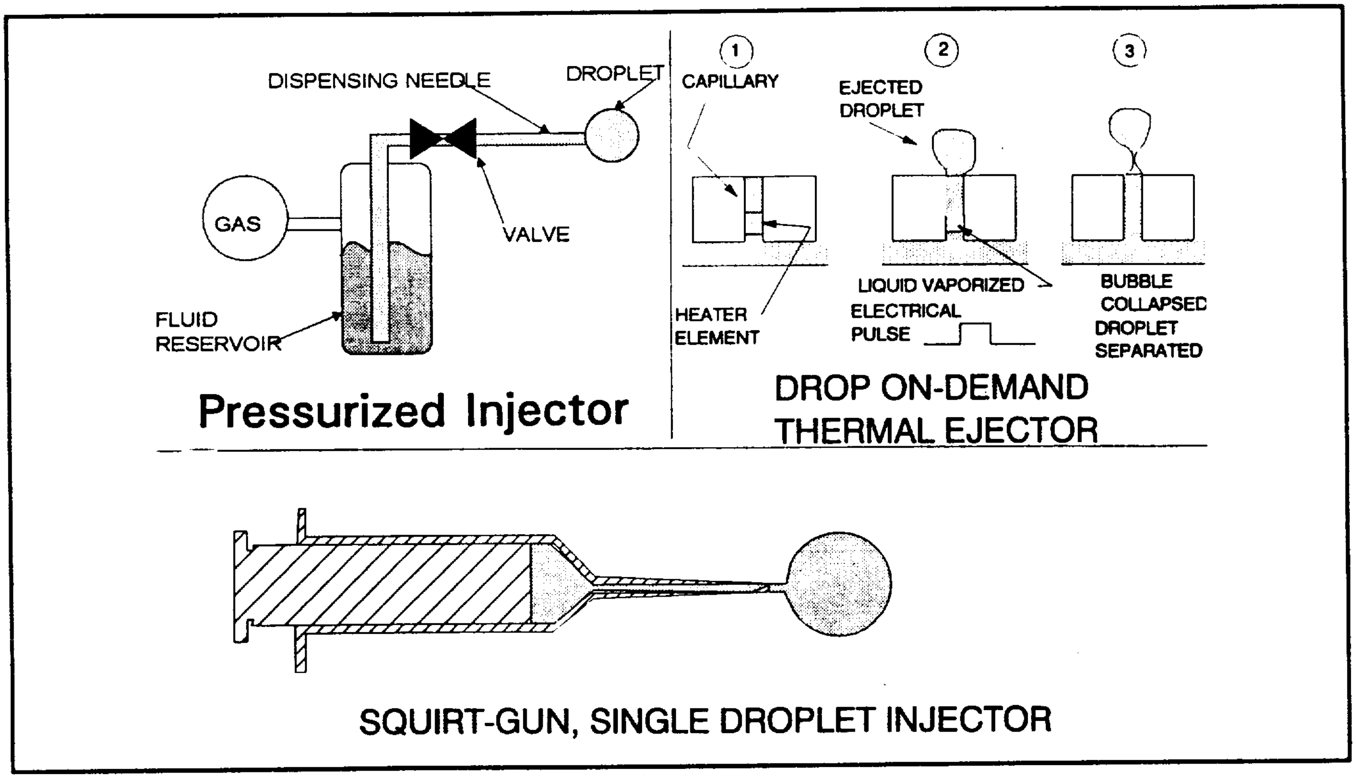
Concept	Description	Pros	Cons
Pressure atomizer (used in automotive fuel injection)	Liquid is fed through nozzle at high pressure where shear force breaks the liquid into droplets. Movable pintle in the nozzle provides face shut-off.	Well developed No dribble at start or end of dispensing No carrier gas required Nozzle/pintle geometries may be adjusted for liquid and drop size Gravity independent	Drop size distribution is broad.
Nebulizers	Various techniques that use the energy of pressurized gas to break up liquid into small droplets	High number density of droplets may be obtained	Carrier gas is required Gravity may be required to keep liquid in position
Vibrating Orifice Aerosol Generator	Liquid is pressure-fed through a micron-size orifice which is vibrated to break up the stream. A carrier gas moves the droplets into the chamber.	Very uniform drop size Gravity independent	Liquid must be ultra-pure to avoid orifice plugging When orifice plugs, clean up require disassembly of unit
Spinning disk	Liquid forms a thin layer over a fast spinning disk. Centrifugal force drives the liquid to edge. The unstable liquid breaks into droplets. A carrier gas inertially separates large from small droplets	May be tailored to produce a desired drop size in a narrow cut	Gravity required to keep liquid on disk unless capillary forces are sufficient (requires additional research and technology development)
Dissolved gas in pressurized liquid (used in spray cans)	Liquid with Dissolved pressurized gas, is fed through a nozzle. The pressurant comes out of solution at lower pressure, breaking the liquid into droplets	Very simple technique	Requires matched pressurant with type of liquid Drop size distribution is TBD Gravity dependent (liquid must cover inlet to dip tube
Thermal ejector (used in ink-jet printers)	Small amount of liquid is evaporated with a short (μsec) pulse. Vapor expansion causes the liquid droplet ejection.	No carrier gas Drop(s) on demand Precise size of droplets High repetition rate possible Gravity independent	Technique is dependent on liquid properties (thermal diffusivity, surface tension, viscosity), may not work well with all liquids. Liquid evaporation is unacceptable for biological samples (exp. no. 19, 20) Only for μm-size droplets

4.3.2.3 Single Drop or Single Particle Generator: These devices are used for creating single or few particles. As in other generator types, generators are developed to satisfy as many size and particle types as possible, but are limited with respect to accommodating all single particle types in one or two devices. Development of these generators can be based on techniques currently used on earth, but with the necessary refinements for zero-g operation. Some droplet generation techniques are listed in Table 23 and shown schematically in Figure 17.

Solid particles might best be accommodated by using a robotic manipulator to retrieve pre-made particles from a storage container, and place them in position in the test chamber. This technique will be easier to apply to larger particles, i.e. greater than 1 mm.

Table 23 - Single droplet generator trades.

Concept	Description	Pros	Cons
Thermal ejector	Same as in Table 22 description.		
Syringe (or micro-syringe) with a positive-displacement plunger	Liquid fills the syringe Plunger motion over a known distance dispenses a droplet of a known size	Simple to implement Droplet separation from the needle tip is easy for relatively large drops (relative to needle diameter)	Droplet separation from the needle tip difficult for small drops (relative to needle diameter)
Pressurized volume of liquid controlled by valve	Liquid behind closed valve is pressurized. Valve is opened for period that is calibrated to deliver required fluid quantity.	Design has been built and tested for flight applications. Droplet separation is easy for droplets that are large relative to needle diameter.	Droplet separation is difficult for droplets that are small relative to needle diameter.



Pressurized Injector

DROP ON-DEMAND THERMAL EJECTOR

SQUIRT-GUN, SINGLE DROPLET INJECTOR

Figure 17 - Single particle dispenser techniques.

4.3.2.4 Soot and Smoke Generator: Some experiments are interested in nanometer-sized particles such as those generated as soot or smoke. These can be accommodated by developing a combustion generator. Several types have Space Shuttle history in the study of materials development and flammability. The systems used on the Shuttle should be investigated for adaptability to the GGSF since their flight worthiness and safety issues have already been addressed. Soot and smoke generation methods are listed in Table 24 and schematically shown in Figure 18.

Table 24 - Soot sample generation trades.

Concept	Description	Pros	Cons
Soot generated in a continuous flow diffusion flame	Fuel (gaseous hydrocarbon) and oxidizer (air) are fed separately into a combustion chamber, mixture is ignited, products flow from combustion chamber to experiment chamber. Combustion is extinguished by shutting off the reactant flow.	• Reaction in a constant pressure (atmospheric) reduces potential hazards • Most common technique for soot investigations	• Safety concerns associated with stored combustibles and flame. • Experiment chamber must be flushed with reaction products several times to establish the proper environment
Soot generated in a premixed fuel/oxidizer closed volume chamber as a batch process	Fuel rich mixture is admitted into chamber and ignited. The high temperature induces decomposition of the remaining fuel, and soot is formed. The contents is transferred to the experiment chamber.	• Batch process with a preset amount of reactants	• Soot properties may be different from soot generated in a diffusion flame • Safety concern for combustibles and combustion in a contained volume
Electrical arc for the vaporization and ignition of high temperature metals (e.g., Mg, etc.)	Probe of desired material is inserted into arc and rapidly vaporized.	• Rapid vaporization	• Contamination may result from electrode wear. • EMI is extensive.

4.3.2.5 In-situ Sample Generators: These are devices intended to assist, enhance, or promote generation of species from gases or liquids. The generators are sources that provide light or radio frequency (RF) radiation. These can be simple units that fit into the standard generator ports of the test chamber, and radiate into the area of interest. The planned units include an ultraviolet light source and an RF generator. Extra concern will need to be given to the RF generator, to contain the radiation.

4.3.2.6 Condensates Generation: The condensates are formed by boiling a sample, and introducing it into the chamber. This can be accomplished using a sample generator that boils the sample, or by adding a sub-chamber in place of the sample generator that can boil and mix the sample with gases prior to introduction to the chamber. The boiler will be an electrically heated oven that uses surface tension of the molten metal to retain it, allowing the vapor to offgas into the

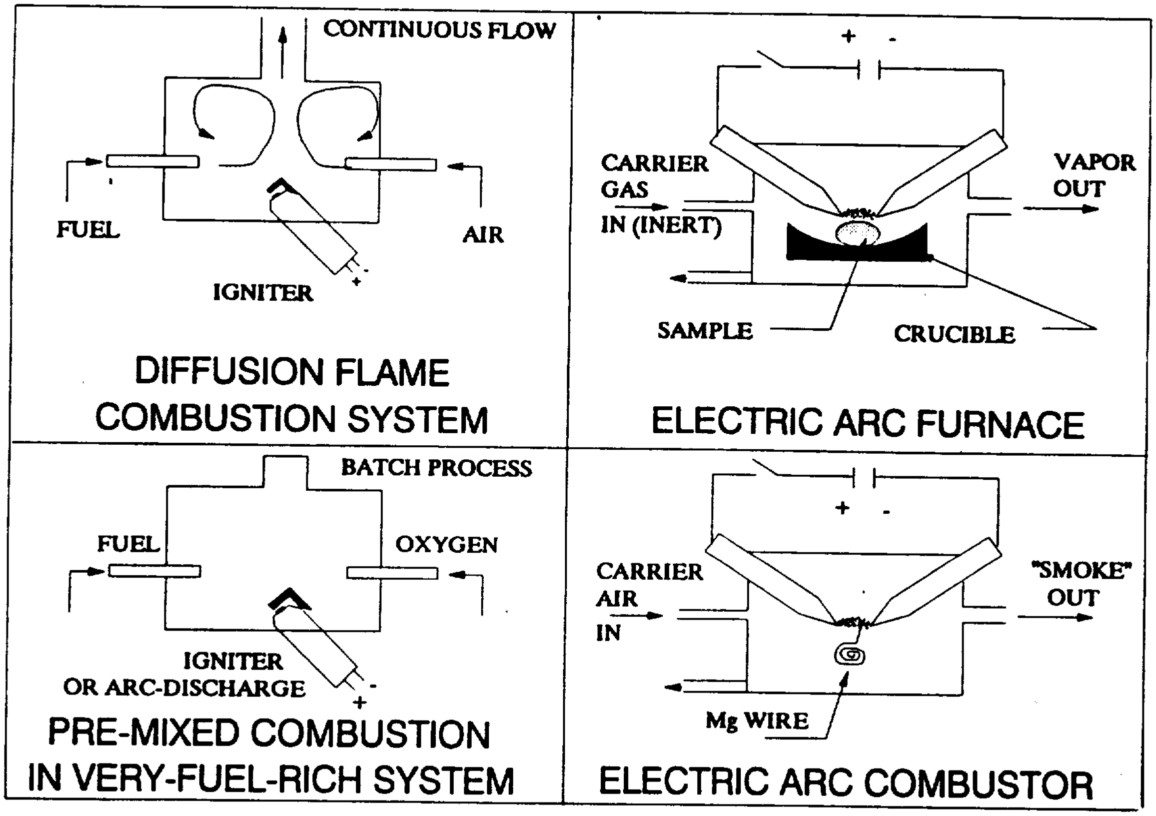


Figure 18 - Soot generator concepts.

test chamber or mixing area of the sub-chamber.

4.3.3 Diagnostics Subsystem - Table 25 shows the experiment requirements for various types of diagnostics. Since the functional requirements are very broad, a range of techniques and instruments are required to meet the GGSF diagnostics requirements. The Subsystem is logically divided into sample diagnostics, and environment monitoring diagnostics. The sample diagnostics are both on-line, being part of the experiment and operating during experimentation, and off-line which requires sample extraction and is performed at a later time on SSF or on earth.

4.3.3.1 On-Line Diagnostics: The conceptual design of the on-line optical diagnostics instrument combines several measurement techniques into a consolidated package. The versatility is provided by modularity and by redundancy. The general design elements in the sample diagnostics are listed schematically in Figure 19. These drivers affect the overall specifications of the

Table 25 - Summary of Diagnostic Requirements.

Measurement	Exp. #
Scattering/Extinction/Diffraction	
Mean Size Distribution (single, cluster)	1
Droplet/Particle Size Distribution	3,5,8,9,10,11,13,14,15,18,19,20
Concentration (or Number Density)	3,8,13,19,20,21
Spectral Extinction & Scattering	5,7,9,10,15,16,21
Forward & Angular Scattering	6,8,10,12,14,16,18,19,20
Emission Intensity; Initial, and Function of Time	9
Size by Polarization (Function of Angle)	7,13
Index of Refraction of Sample	14
Imaging/Video/Photography	
Encounter Geometry (Particle Collision)	1,2
Collision Velocity	1,4
Observe Collision/Impact	1,2
Position & Relative Particle Motion	2,4
Aggregate Fractal Geometry	5,10,13,16
Wall Deposition Materials	5
Position of Sample Cloud	15
Photography; Image at End of Experiment	7,8
Microscopy	8,4,5,12
Other Optical Methods	
Fluorescence; Emission	2,17
FTIR	8,9
Sample Removal	
In-Process Sampling of Experiment Samples	11,19,20,21
Miscellaneous	
Dielectric Loss	13
Laser Doppler Broadening	13
Particle Shape	14
Particle Structure	21
Relative Abundance of Species	1
Bulk Density of Fill Factor and Mass	1
Particle Rotation	4

diagnostics instruments. Concerns and decisions for the diagnostics were discussed in Volume I of in detail.

In general, the on-line sample diagnostics instrument package is divided into three assemblies: (1) radiation source, (2) wavelength selector, and (3) detectors. The configuration is shown schematically in Figure 20.

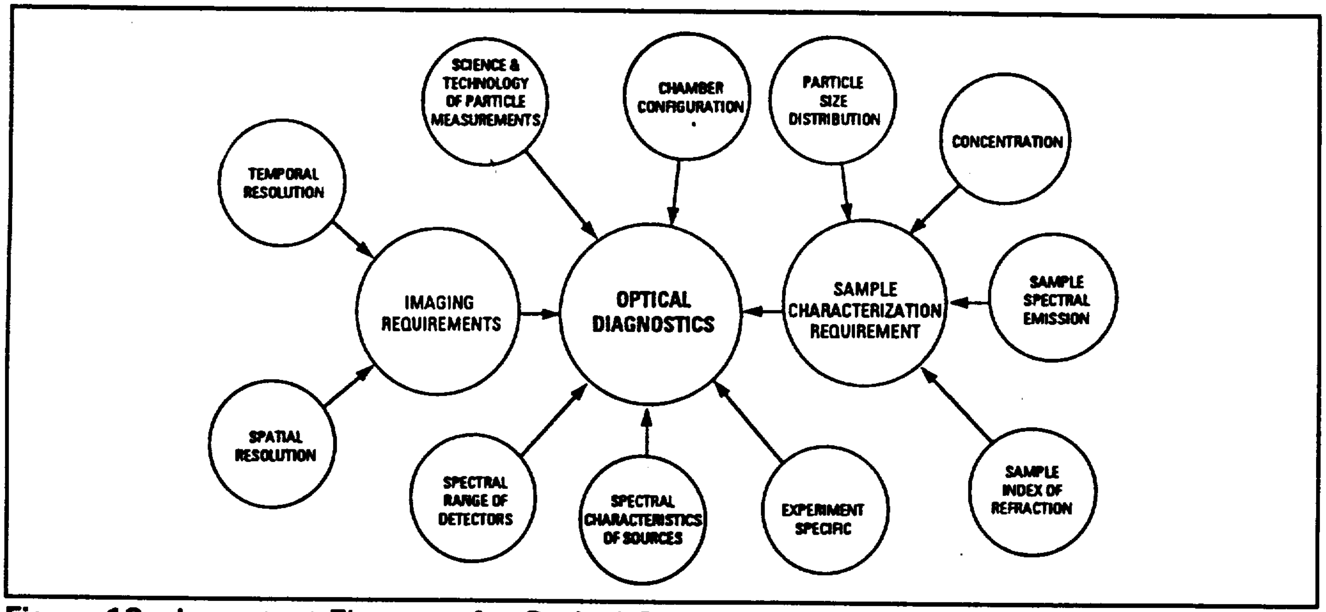


Figure 19 - Important Elements for Optical On-line Diagnostics Design.

4.3.3.1.1 Illumination Source Type. Two source type subassemblies are provided; a monochromatic source (e.g., HeNe laser), and a broadband source (e.g., lamp). Both subassemblies are built into the system, but only one can operate at a time. The source is selected via a hinged mirror that channels one or the other source into the chamber as shown in Figure 20. The lamp subassembly is interchangeable and can accommodate various types of sources for broadband or line emission across the spectrum from the UV to the IR.

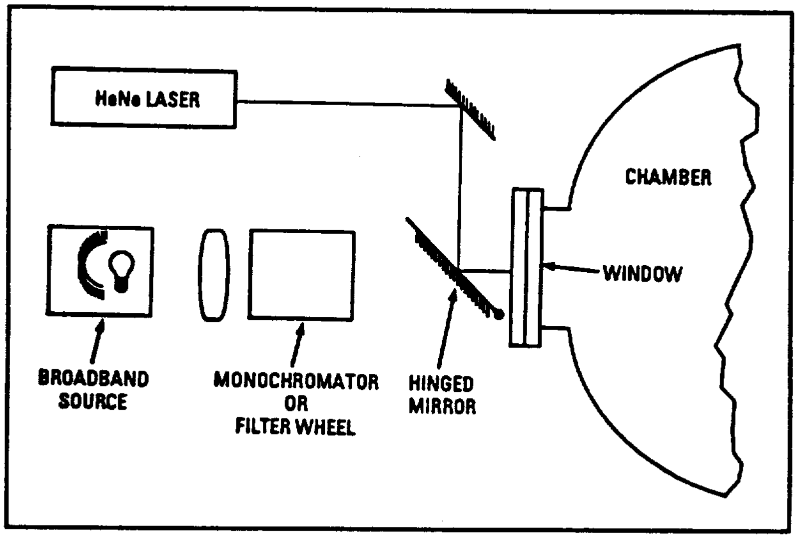
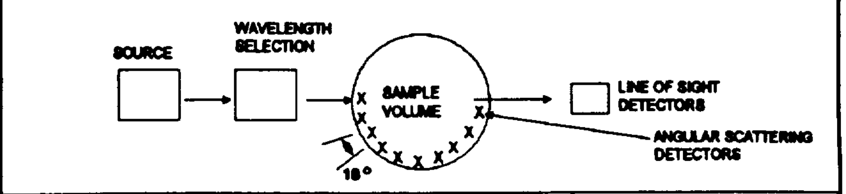


Figure 20 - Optical Diagnostics Light Source Schematic.

4.3.3.1.2 Wavelength Selection. Two options were reviewed for this subassembly. The S&T requirements are not specific enough yet for making the selections. The options are for a monochrometer or a filter wheel located outside the chamber as shown in Figure 20. The actual selection may be determined on the basis of the bandwidth requirements and the number of spectral bands. Figure 21 shows the methods intended.

4.3.3.1.3 Detectors. Several detectors are provided. The line-of-sight detector is the positioned on the window opposite to the radiation source entrance. This detector is interchangeable, depending on the type of source in use. For visible and near IR radiation, a silicon detector is used. For detection of IR radiation, several options are listed in Figure 21, depending on the specific band of radiation. Since the GGSF is not using cryogenics, only thermoelectric cooling is possible and detectors requiring cooling below about 250 K are not recommended. Although Joule-Thompson cooling is possible but it has a limited performance time and may not be appropriate for the GGSF.



SOURCES TYPE	WAVELENGTH SELECTOR	DETECTORS
MONOCHROMATIC - LASER (E.G. He Ne)) BROADBAND (E.G. TUNGSTEN LAMP) -UV -VIS -IR CONTINUOUS SPECTRUM GAS EMISSION (E.G. DEUTERIUM, XENON) -UV -VIS -IR LINE SPECTRUM (E.G. Hg)	MONOCHROMATIC - CONTINUOUS WAVELENGTH SELECTION - HIGH SPECTRAL RESOLUTION - REQUIRES INTERCHANGEABLE GRATINGS FOR BROADBAND FILTERS - LIMIT SPECTRAL BANDS - LOWER SPECTRAL RESOLUTION	PMT: UV-VIS (UNCOOLED) SILICON: UV-VIS-NIR (UNCOOLED) PbS/PbSe: NIR-MWIR (UNCOOLED) InSb/PtSi: MWIR (COOLED) HgCdTe: MWIR-LWIR (COOLED) SIX: LWIR (COOLED, LHe)

Figure 21 - Light sources and detectors.

In addition to the on-line detector which is external to the chamber, a ring of detectors is installed internally for the measurements of the angular scattering of radiation. These detectors are also shown schematically in Figure 21. Since the internal detectors are not easily accessible, only silicon detectors are provided. Each internal detector comprises a linear diode array with a lens for collecting the radiation from the center of the chamber. The laser beam is in the plane formed by the ring. To prevent exposure of the detectors to radiation from adjacent positions in the chamber (confusing the angular position of the radiation) spatial filtering is provided as shown in Figure 22. The two lenses shown in Figure 22 are anamorphic lenses that produce a linear image over the detector array. This arrangement significantly improves the optical efficiency of the assembly. Ten assemblies of linear arrays with the required optics are provided 18° apart, while the forward scattering is measured with the external line-of-sight detector.

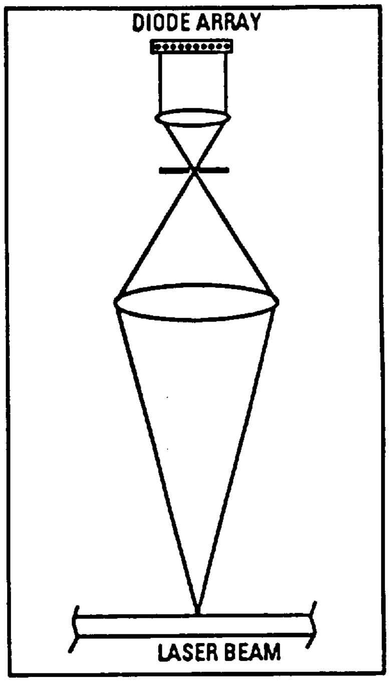


Figure 22 - Spatial filtering technique.

The overall sample diagnostics package can perform the following additional types of sample diagnostics measurements.

- Spectral scattering is performed by scanning the source spectral radiation either via the monochrometer or the filter wheel.

- Detection can be performed with any of the detectors described above.

- Polarization of the radiation by small particles can be detected by introducing the appropriate filters in front of the detectors.

- Turbidity or absorption is performed using the source (broadband or monochromatic) and the on-line detector.

- Diffraction measurements are done by the use a beam expander for the laser source and a linear diode array in place of the on-line detector. This technique is shown in Figure 23.

- Emissions/Fluorescence are detected with any of the detectors set up in the system, and is shown in Figure 24.

The package is flexible enough to allow the selection of the most appropriate technique for the given sample conditions. A summary of the optical package capabilities is shown schematically in Figure 25.

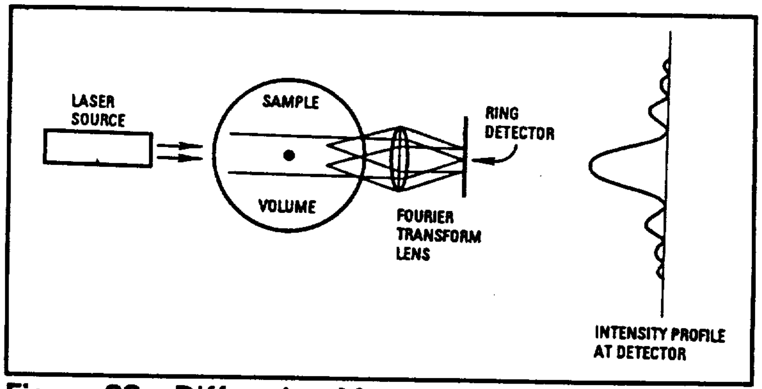
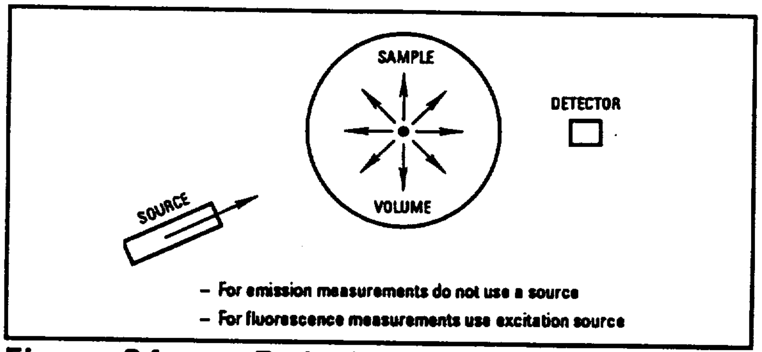


Figure 23 - Diffraction Measurements Concept.



– For emission measurements do not use a source
– For fluorescence measurements use excitation source

Figure 24 - Emission and Fluorescence Measurements Concept.

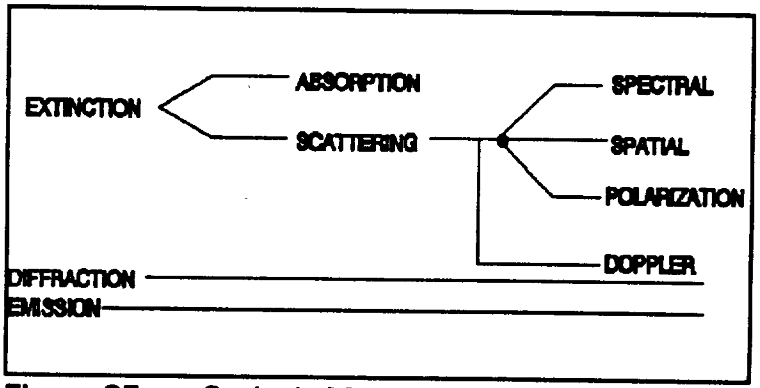


Figure 25 - Optical Measurements Provided for Sample Characterization

4.3.3.1.4 Imaging.
The imaging assemblies is comprised of two CCD camera heads positioned at 90° apart to provide three coordinates of motion tracking. The camera heads are positioned on tracks to allow interfacing with the different chambers. Data recording capabilities include an analog VCR, video digitizing as modular capability of the Electronics Subsystem, and a digital still camera. Lighting for the video includes front lighting for one camera and back-lighting for the other.

The specific CCD format selection is TBD pending clearer S&T requirements definition. A zoom/macro lens is provided for the selection of the field-of-view (FOV) and magnification. The zoom setting is motorized but no feedback control is necessary. Real-time video link is not provided to ground, requiring zoom to be defined by the experimenter in advance during untended operation. A video monitor is provided to allow the experimenter to adjust the setting while viewing the video monitor during tended operations.

4.3.3.1.5 In-Chamber Experiment-Specific Diagnostics. Provisions are provided for the mounting of experiment-specific diagnostics (e.g., Vol. I, Table 25). Internal mounting points used primarily for mounting the detector ring can be used for mounting other specific assemblies when the detector ring is not in use. In addition, each chamber has two sample generation ports with a standard configuration interface. Experiment-specific diagnostics can be inserted into the chamber through any one of these ports and mounted onto the standard interface.

4.3.3.2 Off-Line Sample Diagnostics: Particle size and concentration levels outside the range of the on-line optical diagnostics will be characterized using off-line instruments. Several commercially available techniques are appropriate but the commercial instruments will have to be modified to meet the GGSF constraints. The diagnostics subsystem includes the required interfaces for these instruments, and the software and hardware required for utilizing these instruments. The following off-line instruments, with appropriate modifications, can be considered.

- Condensation nuclei counter (CNC) capable of measuring particles roughly within the range from 0.01 to 2 μm, and concentrations up to 10^7 particles/cm^3, or down to 0.003 μm at concentrations of 10^5 particles/cm^3.

- Diffusion battery for particles in the range 0.005 to 0.2 μm and a very broad concentration range from 0.001 to 10^7 particles/cm^3.

- Electrical mobility analyzer with a range from about 0.01 to 1.0 μm and concentrations from about 1000 to 10^7 particles/cm^3.

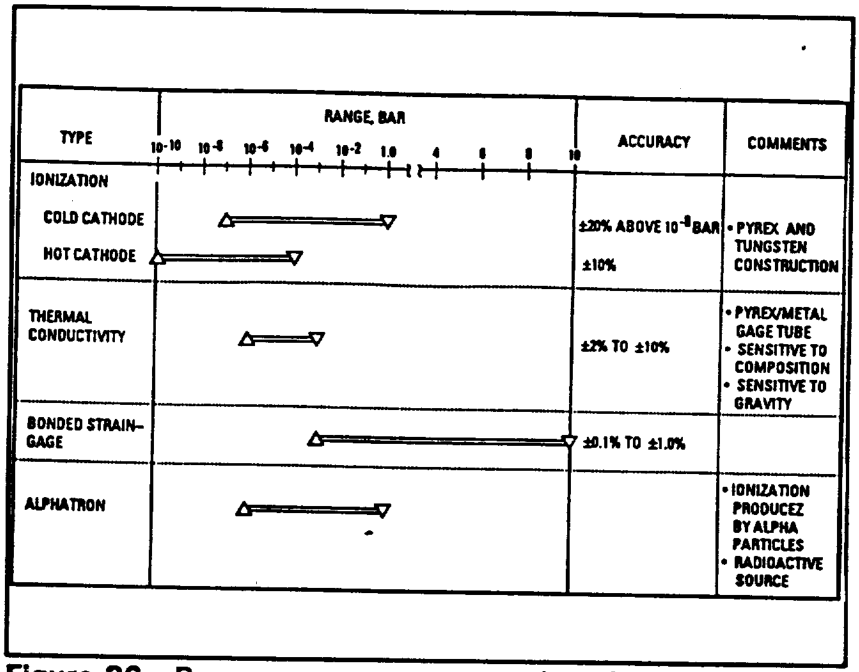
These instruments are often used in conjunction with each other and GGSF can provide two interfaces points for a combination of two instruments. The sample extraction from the chamber to the particle counter can be accomplished using a sampling probe and the VRS vacuum providing the suction.

4.3.3.3 Environment Monitoring: The test will have the capability to monitor pressure and temperature. The humidity will be determined in the mixing chamber prior to introduction to the test chamber, and humidity samples can be taken in the test chamber for monitoring purposes. A miniature gas chromatograph concept, like TRW device used in interplanetary missions, is included in the design to measure gas composition.

4.3.3.3.1 Pressure Measurements. Due to the extremes in measurements, two different pressure gauge types are necessary.

Gauge Selection. A comparison of the performance of pressure sensors applicable for the GGSF is shown in Figure 26. In order to cover the complete operating pressure range for the experiments, two gauges will be provided, one for the low range and one for the high range. A common strain-gage type of device is adequate for higher pressures of one millibar and up.

For pressures below a millibar, a different type of gauge is required. It should be noted that the accuracy of the vacuum sensors is in the range of ±10% to ±20%. For experiments conducted over several orders of magnitude in pressure, i.e., from 10^{-10} to 10^{-6} bar, an accuracy of ±20% should be considered reasonable. Therefore, the ionization type gauge was selected as a baseline for the low pressure range.



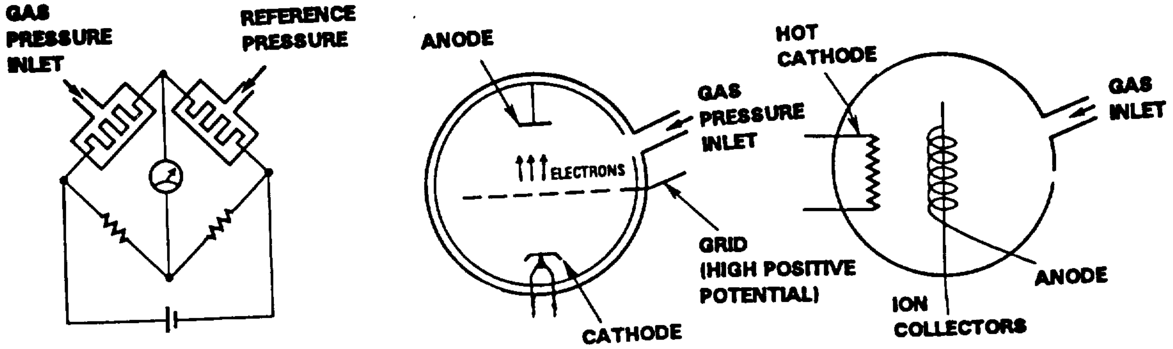
TYPE	RANGE, BAR	ACCURACY	COMMENTS
IONIZATION			
COLD CATHODE		±20% ABOVE 10^{-8} BAR	• PYREX AND TUNGSTEN CONSTRUCTION
HOT CATHODE		±10%	
THERMAL CONDUCTIVITY		±2% TO ±10%	• PYREX/METAL GAGE TUBE • SENSITIVE TO COMPOSITION • SENSITIVE TO GRAVITY
BONDED STRAIN-GAGE		±0.1% TO ±1.0%	
ALPHATRON			• IONIZATION PRODUCEZ BY ALPHA PARTICLES • RADIOACTIVE SOURCE

Figure 26 - Pressure gauge types and performance.

A thermal conductivity gauge is not recommended because (a) it is sensitive to the composition, requiring calibration for every possible new mixture composition, and (b) it is sensitive to the g-level since it measures the thermal conductivity of gases in the presence of natural convection. Since natural convection is proportional to the g-level, in μg a new calibration of the sensor is required.

The principle of operation for the different types of gauges is shown schematically shown in Figure 27.

Gauge Placement. The gauges will be connected to the manifold which is used to fill or evacuate the chamber, rather than directly to the chamber as shown in Figure 28. This allows the



PIRANI (THERMAL CONDUCTIVITY) GAGE

- HEAT LOSS FROM HEATED FILAMENT DEPENDS ON GAS SURROUNDING WIRE
- WIRE COOLING DUE TO NATURAL CONVENTION (GRAVITY INDUCED)
- WIRE RESISTANCE DEPENDS ON TEMPERATURE
- RESISTANCE CHANGE MEASURED BY WHEATSTONE BRIDGE

COLD CATHODE IONIZATION GAGE

- ELECTRONS EMITTED BETWEEN HIGH VOLTAGE ELECTRODES
- ELECTRONS IONIZE GAS MOLECULES
- CURRENT IS PROPORTIONAL TO IONS PRODUCED

HOT CATHODE IONIZATION GAGE

- ELECTRONS EMITTED FROM HOT CATHODE
- ELECTRONS IONIZE GAS MOLECULES
- CURRENT IS PROPORTIONAL TO IONS PRODUCED

Figure 27 - The principle of operation of some types of pressure gauges.

replacement of chambers without replacing the gauge as well. The line connecting the chamber to the pressure sensor should be as wide as possible in order to improve conductance for low pressure measurement. Otherwise the difference between the actual chamber pressure and that measured by the gauge may be significant.

Isolation. An isolation valve will be provided to isolate the gauges from the line during experimentation outside the operating range of the gauge, and to avoid gauge contamination by particulate matter during the evacuation of the chamber.

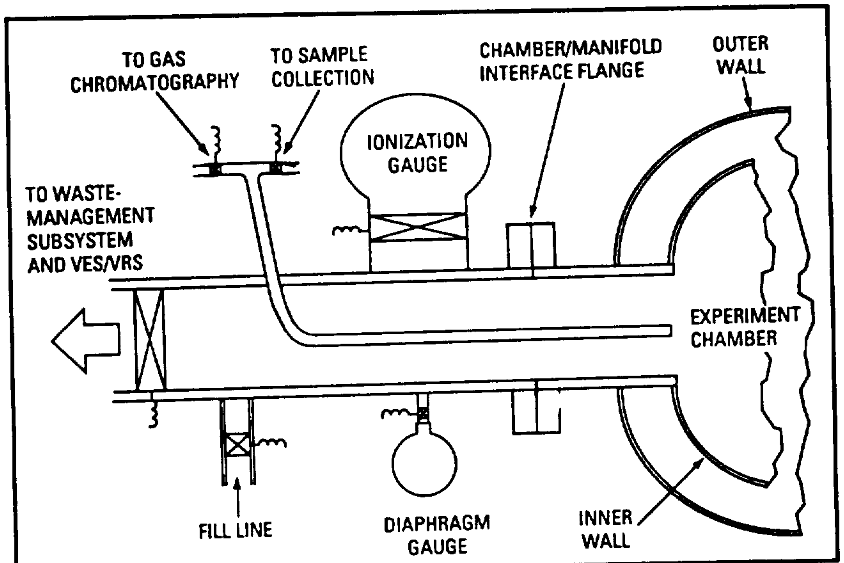
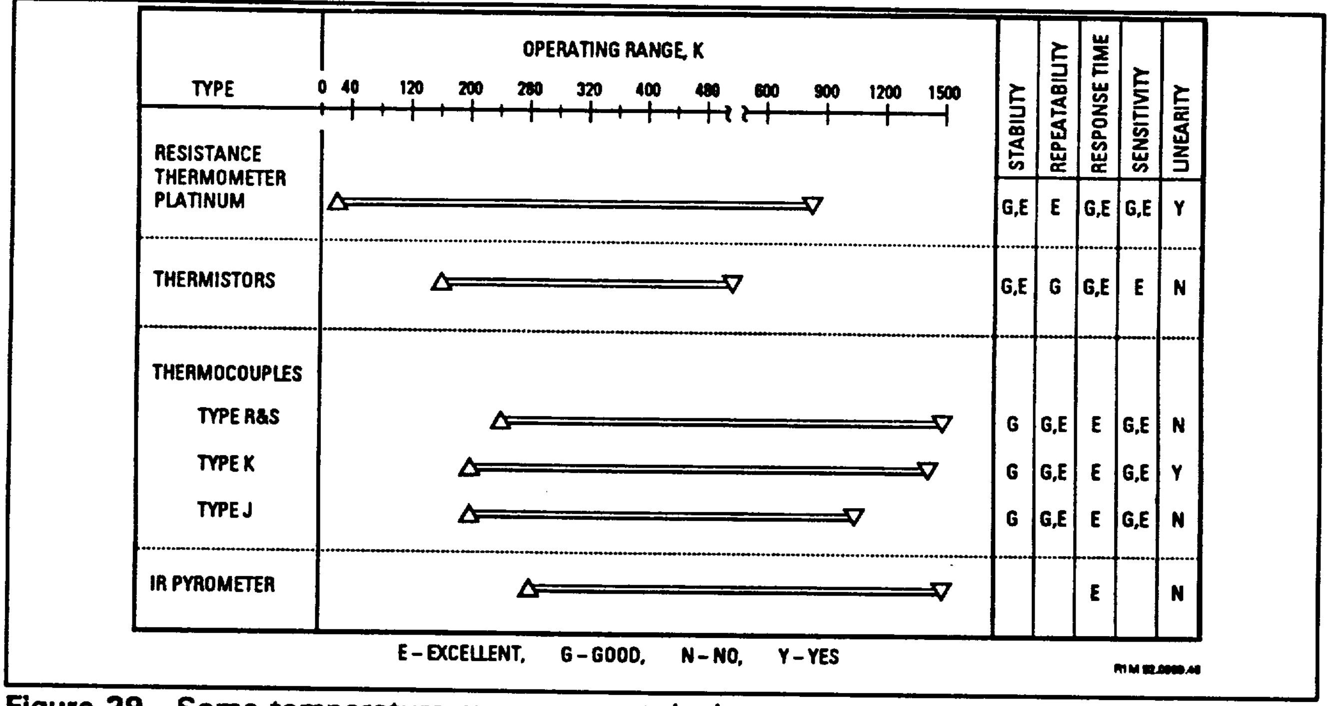


Figure 28 - Method of monitoring several environmental parameters of the test chamber.

4.3.3.3.2 Temperature Measurements. Temperature measurement accuracy may drive the design to multiple sensor types, located in various locations. A summary chart of temperature sensors applicable to the GGSF is shown in Figure 29. Platinum RTD seems to provide the best performance over a wide temperature range. Type R, S, or K thermocouples are provided for the high end of the temperature range for the high-temperature chamber.

Inner wall temperature sensors are provided at three TBD locations. These sensor will provide information on wall temperature gradients and cooling rate. Additional two sensors are provided to measure the gas temperature in the chamber. These two sensors protrude through the wall and are exposed to the internal chamber atmosphere. Outer chamber wall temperature will also be monitored at two separate locations.



TYPE	STABILITY	REPEATABILITY	RESPONSE TIME	SENSITIVITY	LINEARITY
RESISTANCE THERMOMETER PLATINUM	G,E	E	G,E	G,E	Y
THERMISTORS	G,E	G	G,E	E	N
THERMOCOUPLES					
TYPE R&S	G	G,E	E	G,E	N
TYPE K	G	G,E	E	G,E	Y
TYPE J	G	G,E	E	G,E	N
IR PYROMETER			E		N

E - EXCELLENT, G - GOOD, N - NO, Y - YES

Figure 29 - Some temperature measurement devices.

4.3.3.3.3 Moisture Monitoring. A hygrometer can be used to monitor the humidity in the test chamber. The experiment requirements are still vague with respect to measurement accuracy. The desired control of up to 0.01% implies an accuracy of at least that well. The same device is used in the mixing chamber, where the moisture is added to the gas. The speed and accuracy of these types of devices depend on movement of the sample air through the device, which can be an option within the device itself, however the effect of this movement needs to be evaluated against the experiment requirements for a still environment.

Devices are available that can be adapted to the GGSF. The MCM Dewlux, selected as a reference, can meet the accuracy requirements, can be used in high vacuum and up to 300 atmospheres, and from -80C to +95C temperatures. This unit weighs 13 pounds in a standard rack-mounted configuration with a remote sensing head, but could be miniaturized and light-weighted for our GGSF application.

4.3.3.3.4 Gas Composition Measurements. A gas chromatograph is used to measure gas composition. Samples can be extracted from either the gas mixing chamber or the test chamber. Test chamber samples will need to be filtered to keep particles out of the valves. Though a requirement for pyrolysis has not been identified, the gas chromatograph can be used to analyze these types of samples, should the need arise.

Gas chromatographs have been designed for low power and light weight space applications such as the Viking Lander and Pioneer Venus. These units exhibit a significant size reduction over commercial devices. The gas chromatograph will vent to the SSF vacuum system, which is schematically indicated in Figure 30.

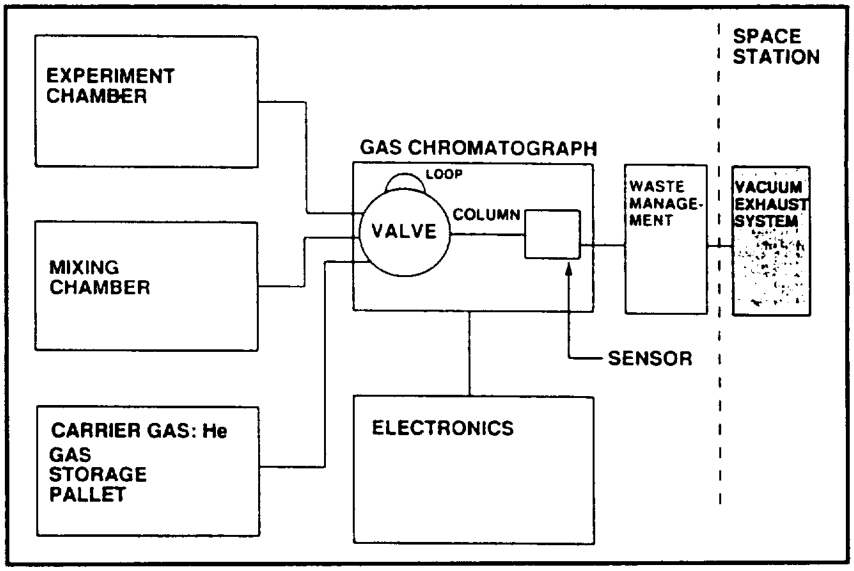


Figure 30 - Schematic Installation of Gas Chromatograph.

4.3.4 Sample Collection Retrieval and Storage Subsystem - This subsystem will consist of several methods in order to meet the requirements of the experiments. The requirements still need better definition to complete the design of this subsystem. Some methods for particle retrieval are proposed to meet some expected requirements.

A method for sampling small particles is to pass the particles in a carrier gas through a filter module in the Waste Management Assembly. This might be an impactor, or small-pore filter. Another method is the use of an intrusive sample collector provided by the facility user, that accesses the particles through one of the generator ports in the chamber. Once the particle is collected, the filter (or custom holder) may be removed for off-line analysis or storage.

The storage of the collected samples may require experiment specific containers which satisfies the needs of each stored sample. For those retrieved for return to earth, the container should be accommodated in the storage drawer that is used for transporting facility items between earth and SSF. Some samples may require cold storage which can take advantage of the SSF LSE refrigerator.

4.3.5 Gas Handling Subsystem - The Gas Handling Subsystem is designed to accommodate the requirements for providing and interchanging various gas mixtures into the test chamber. The major assemblies associated with this subsystem are the gas supply assembly, the gas mixing assembly, and the waste management assembly. Each of these assemblies provide distinct functions, tied together by piping and valves that accommodate automated control. A GGSF schematic system is shown in Figure 31.

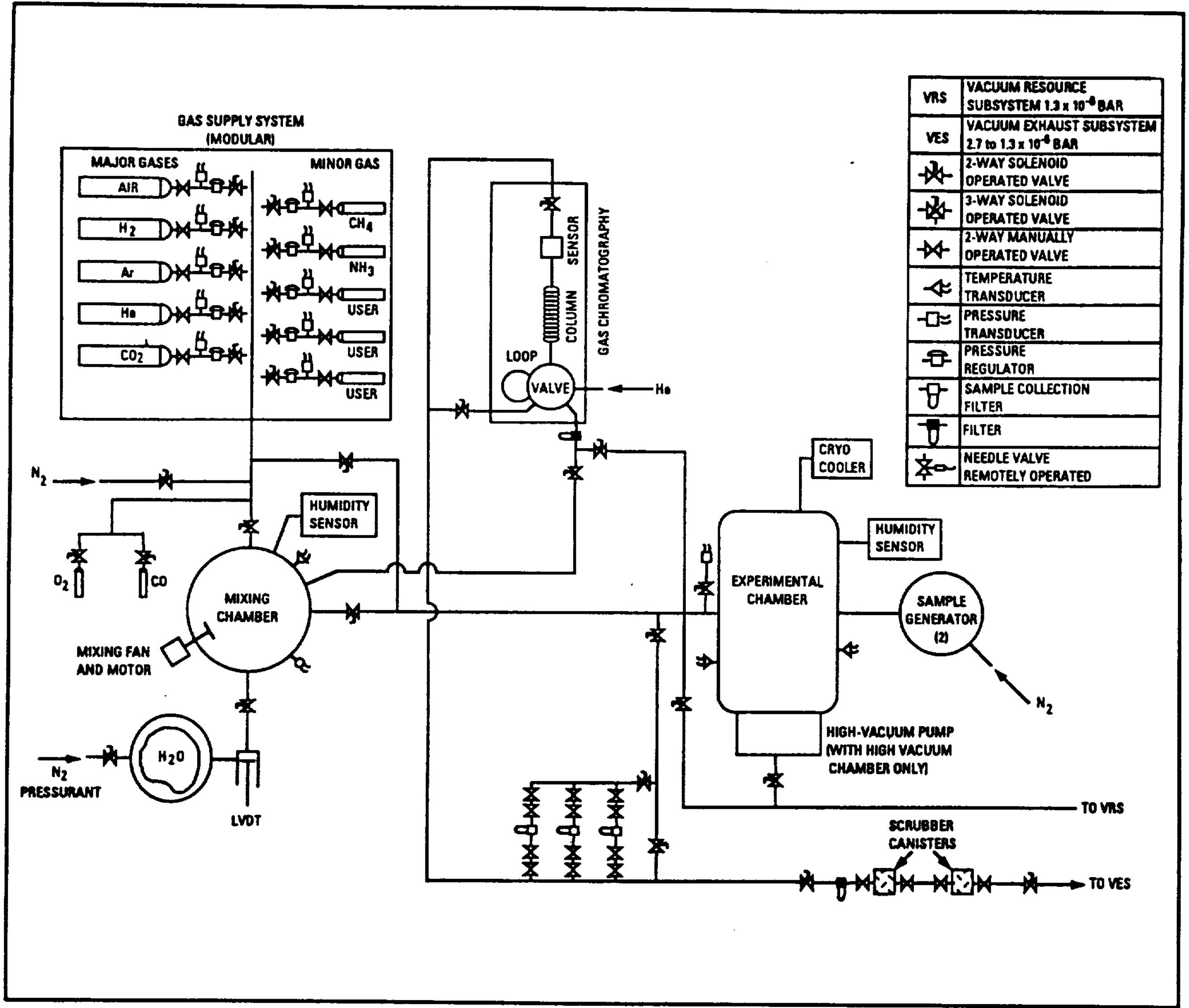


Figure 31 - GGSF Plumbing Schematic

In the GGSF design, the Gas Supply Assembly is utilized to store the often-used gases in their pure form. The Gas Mixing Assembly provides mixing of the gases. Without the assistance of natural or forced convection, this process would be very slow. This subsystem also has accommodations for three experiment specific gas mixtures which can be provided by the experimenter in standard bottles, for those cases where the facility-provided gases don't fulfill the gas requirements of that experiment.

4.3.5.1 Gas Supply Assembly: This assembly provides a series of common working gases on the facility which can be stored in fairly large quantities for use by all experimenters. The gas bottles may be removed individually or the Gas Bottle Rack may be removed as a unit. This provides for earth return to refill and transport back to SSF. A manual valve is attached to each bottle, and travels with that bottle. A disconnect is provided between each bottle and a manifold which is part of the rack. This manifold contains pressure regulators, metering valves, and solenoid valves which are controller operated during fill of the test chamber or mixing chamber. Metering of the gases provides the ability for the controller to deposit various amounts of the different gases into the chambers for different experiments.

The gases that are required most often are stored in 8200 cc tanks, while the ammonia and methane are stored in 4000 cc tanks. Small amounts of oxygen and carbon monoxide are required, and are stored in 500 cc tanks. The user-provided tanks can be up to 4000 cc, and three of them can be accommodated at one time. The selected gas storage tank design is a graphite epoxy over-wrapped on an aluminum shell based on existing tank technology. These vessels meet the requirements of MIL-STD-1522A, as referenced by NSTS-1700.7B. The tanks can be pressurized to 340 atmospheres, with a burst factor of safety of 2.0, and are designed to leak before bursting. The properties of the tanks are indicated in Table 26.

Table 26 - Gas Storage Tank Use and Properties.

Stored Gas	Volume (cc)	Weight, empty (kg)	Weight, full (340 atm) (kg)	Outer Diameter (cm)	Length (cm)
Air	8200	3.6	6.8	18	56
Hydrogen			3.8		
Argon			7.6		
Helium			7.0		
Carbon dioxide			8.4		
Ammonia	4000	2.2	7.4	14	40
Methane			3.1		
User-provided gas (3 bottles)			n/a		
Oxygen	500	0.2	0.4	5	53
Carbon monoxide			0.4		

4.3.5.2 Gas Mixing Assembly: Mixing of gases without the benefit of convective currents is a very slow process. For this reason, a Gas Mixing Subsystem is provided to enhance this process. Figure 32 shows the method of using a mixing chamber in the GGSF. Gas is fed to the mixing chamber from the gas storage bottles. The mixing chamber contains a mixing fan, pressure and temperature monitors, and a moisture injection device for humidification of the gas mixture. The controller monitors this device for safety, and can open a valve to the waste management system for relieving pressure in case of a failure which increases pressure beyond a safety set point. Evacuation can also be performed this way, to decontaminate the chamber for future experiments.

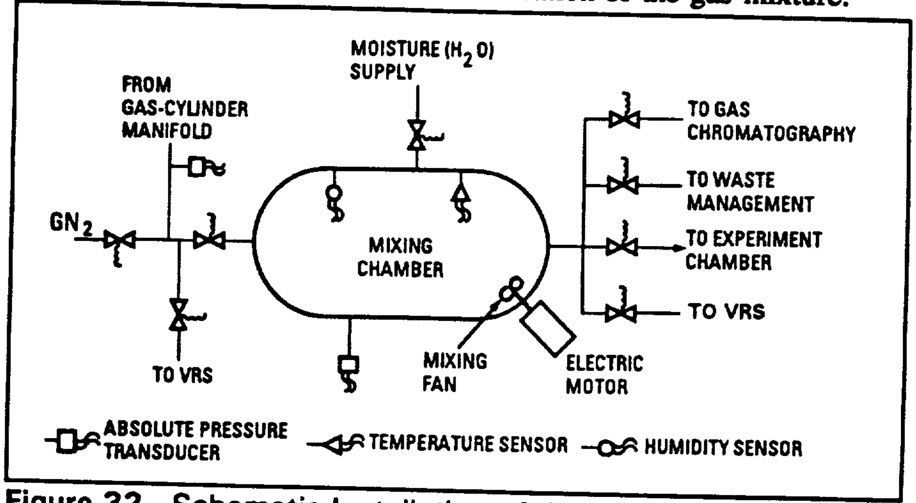


Figure 32 - Schematic Installation of the Gas Mixing Chamber.

4.3.6 Waste Management Subsystem - This subsystem is the experiment effluent interface from the facility to SSF. It incorporates the valves and manifolding to accommodate automated evacuation of the test and mixing chambers, as well as gas scrubbing and sample collection.

4.3.6.1 Vacuum: The approach to providing vacuum capabilities for the GGSF is based on the use of the SSF VRS which can provide vacuum to the 10^{-6} bar level. The VRS satisfies all the experiments except number 17, which requires 10^{-8} to 10^{-10} bar. The use of the VRS requires timeline coordination with other VRS users to avoid cross contamination and back-streaming. A separate vacuum pump to assist to the VRS is not recommended because of the added complexities in interfacing the pump to the chambers. With the proper isolation valves, the VRS can provide the required vacuum capabilities. The pumping speed depends on the VRS interfaces which are TBD.

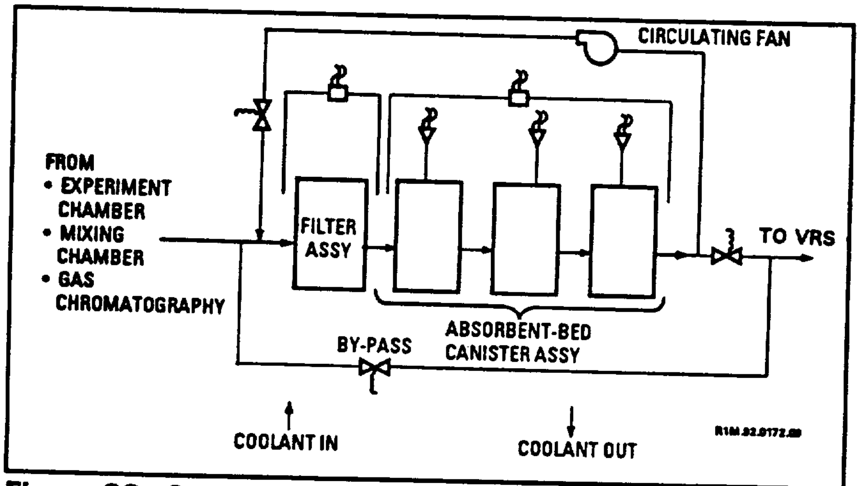


Figure 33 - Schematic of the Waste Management Assembly

4.3.6.2 Sample Collection & Storage: The detailed definition of the sample collection subsystem depends on the characteristics of the samples, which will vary considerably, and still require detailed definition. Most collection techniques are dependant on flow of a carrier gas. For experiments that are performed under vacuum, the sampling efficiency of these types of devices may be very low.

Particulate (solids or liquids) samples are collected from the experiment chamber by drawing out a gas sample and flowing the sample through a collection device. The sample collection device is connected to the VRS (vacuum) thereby drawing the sample from the chamber. A sample probe can intrude through a chamber port or be flushed with the wall, depending on the volumetric homogeneity of the sample.

The collection device may be an on-line filter with a specific filter element selected for the application. The collection efficiency is a function of the particle size and material. Filter material properties can be selected to accommodate many of the requirements. The collection device could be a single stage or cascade type filter or impactor.

The collection filter is removable for sample retrieval. The filter is not equipped with any thermal control for preservation of ices or other situations.

Sampling of single particles, and sampling of fragile particles can be accomplished using a sample generation port that can be equipped with an experiment-specific retrieval device. Preservation of fragile samples will be provided in a specifically defined volume in the GGSF. Requirements for vibration control and thermal environment control in the storage have not been defined.

4.3.7 Electronics Subsystem - The Electronics Subsystem provides experiment control, data acquisition and storage, analyses, and SSF interfaces. A block diagram of this subsystem is shown in Figure 34.

The experiment control electronics consists of two general elements. The first element includes those components that are interchangeable and support/control other interchangeable hardware modules such as sample generator, various chambers, diagnostics units, etc. These elements contain local capability for control and data acquisition, and they digitize signals for noise reduction. The second type of element is "fixed" in the GGSF and provides communications and control, interface with the operator, interface to the U.S. laboratory and the utilities, transmission of image and data to, and receiving commands from, the U.S. laboratory module or ground control. This element includes the display monitors, other user interfaces such as keyboard or touch panels, and the computer. Table 27 and Table 28 show the sectors for each electronics package, and their functions.

Because of the longevity requirements of the GGSF, the design includes a modular payload computer system that allows for an upgrade of the system. In addition, modules for supporting experiment specific hardware or additional facility capabilities are independent plug-in boards that are installed into a passive-backplane-configured system.

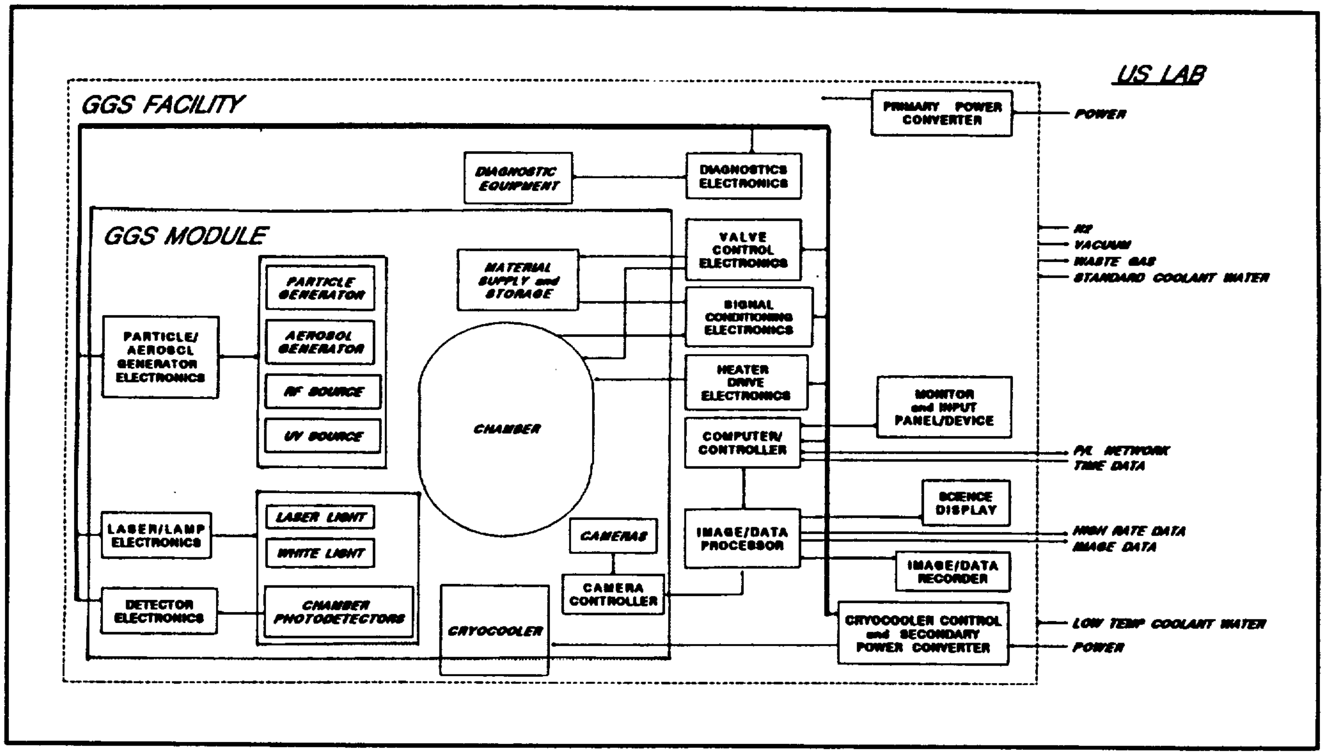


Figure 34 - GGSF Electronics Block Diagram.

Table 27 - Removable Electronics to Support Interchangeable Hardware.

SECTOR	FUNCTION
• Particle/Aerosol Generator Electronics	• Controls specific needs of particle generator including isolation valves, feed flow valves, heaters, motors ignition, RF • Acquire specialized flow, pressure, temperature, etc. sensors needed for specific particle/aerosol generators • Local microprocessor used to ease change-out to specific experiment needs • permits experimenter to work and refine in own lab
• Laser/Lamp Electronics	• HeNe Laser • Lamps -Xe, H_2, Hg, etc., for light source UV for material excitation • Localized to laser/lamp assemblies to accommodate change-out of test sources
• Camera Controller	• Motor controller to allow zoom to enhance image of small particles • Motor controller to allow focus to full depth of view in chamber • Provides variable integration time and variable frame speed • Local microprocessor to provide proper sequencing for CCD operation
• Detector Electronics	• Preamps for photodiodes which detect density and scattering data • A/D converter to digitize signal for noise reduction

Table 28 - "Fixed" Electronics.

SECTOR	FUNCTION
• Diagnostic Electronics	• Particle counter electronics • Heater control • Gas Chromatograph (or similar) data acquisition and control • Local A/D for transmission to computer/controller and noise reduction
• Cryogenic Cooler Electronics	• Cryocooler power supply and control switch
• Valve Control	• Control routing of U.S. lab utilities • Water, N2, Waste gas, vacuum • Particle/aerosol generator electronics • Diagnostics valves • To material supply and storage isolation and feed flow valves • To chamber valves
• Heater Drivers	• On/Off • Proportional heaters • High Temp, High Power
• Signal Conditioning - Sensor Signals:	• Flow, Pressure, Temp, Humidity, Charge, Impact
• Computer/Control	• Controls experiment functions via test chamber electronics • Interface with input panel/device • Run time lines and verifications • Accept commands from P/L network • Interface with test conductor: Keyboard, Monitor/touch panel • Data acquisition • Acquire from test chamber electronics • Acquire from facility electronics • Data transmission • Payload network for telemetry • High rate data interface for high speed diagnostics data (e.g. GC data) • Interface with image/data processor
• Image/Data Processor	• Acquire image/data • Interface with camera controller • D/A conversion to provide NTSC output • Control synchronization of image events • Frame grabber to capture high speed events • Control image/data recorder if required • Provide buffer and storage • Transmit image/data • Include high-speed digitized data • Drive science image display
• Image/Data Recorder	• Additional buffer and storage if required

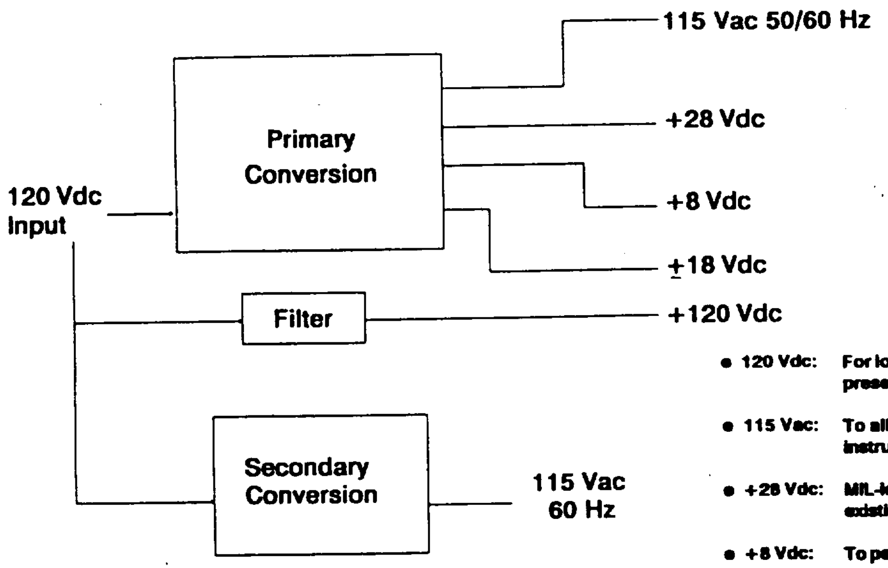
A summary of the methodology for data handling and downlinking to the user is indicated in Table 29.

Table 29 - Planned Data Downlink Methodology.

Type Of Data	Requirement	Real-time Downlink	SSF Data Recording	GGSF Data Recording
Analog Video	Std. NTSC	Requires Timelines	Available	Video recorder
Instrumentation	Digital, Low Speed (100S's Kbits/s)	Requires Timelines	OK	Digital Recorder
Digital High Resolution Video	100 MBytes/s *	Requires Timelines	Requires Timeline & Allocation	Digital Recorder 500 MBytes **

*1000X1000 Imager @100 fps, @ 8 Bit A/D, 5 Seconds of data
**Digital tape, hard drive, or SRAM solid-state memory boards

4.3.8 Power Subsystem - This subsystem provides power conditioning and distribution for the GGSF. Power is conditioned and distributed to the various facility subsystems in a usable form that has been converted from the SSF 120 Vdc source. This unit is subdivided into two assemblies. The primary conversion assembly is centralized for efficiency and easier EMI/EMC suppression. The primary conversion is expected to provide approximately 1,500 watts peak. The secondary conversion is for the cryocooler, and provides 1,500 watts peak. A stand-alone power converter for the cryocooler is preferred, because, being a single-high-power application, it is expected to be a higher noise source. A separate converter also allows for future design alterations without affecting the main electronics supply. Figure 35 summarizes the power management and distribution system, and Table 30 summarizes the details of each unit.



- 120 Vdc: For low-level distribution to allow for presently unplanned additions.
- 115 Vac: To allow local usage of "off-the-shelf" instrumentation equipment.
- +28 Vdc: MIL-level relays, wide equipment selection, existing hardware designs.
- +8 Vdc: To permit local regulation for logic supplies, etc.
- ±18 Vdc: To permit local regulation for amplifiers, signal processing circuitry.
- 115 Vac: For cryogenic cooler and other high high power Applications.

Figure 35 - GGSF Power Management.

Table 30 - Power Converter Design Details.

PRIMARY POWER CONVERTER	Power Watts	Typical Eff., %
●Rated Design, Maximum load	750	87
●Rated Steady-State Average	500	83
●Minimum Steady-State Average	250	72
●Physical Considerations		
-Power dissipation, maximum	112	
-Power dissipation, average	100	
-Size: 30 x 35 cm footprint x 23 cm high		
-Thermal conduction density: 0.6W/in^2		
-Weight: 16 kg		
● Design:		
-4 "slices" for the main outputs		
-Average 2 PWBs per slice + magnetics		
-Selected functional redundancy in voltage and overload circuits where useful to do so		

SECONDARY POWER CONVERTER	Power Watts	Typical Eff., %
●Rated Design, Maximum load	600	82
●Rated Steady-State Average	400	75
●Physical Considerations		
-Power dissipation, maximum load	131	
-Power dissipation, average load	133	
-Size: 30 x 35 cm footprint x 23 cm high		
-Thermal conduction density: 0.79W/in^2		
-Weight: 20 kg		
●Design:		
-2 Fully redundant "slices"		
-Half of each slice dedicated to magnetics		
-Selected protection for over-voltage and overload where deemed useful		

4.3.9 Positioning & Levitation Subsystem - No design work was performed on this subsystem due to the incomplete requirements definition, and the immature status of the technology with respect to GGSF requirements.

4.3.10 Structures Subsystem - This subsystem includes the ISPR and all the brackets, ducts, assembly hardware, and maintenance tools required to accommodate the other facility subsystems into an integrated package. Brackets will generally be aluminum. If thermal insulation is required, titanium is the preferred material. Fasteners are of corrosion resistant steel (CRES), and will be socket head type for ease in use. Commonality of fastener size is desired to reduce the number of tools required to support facility maintenance.

Storage is provided for facility maintenance tools, and velcro attachments are provided on the structure and tools to avoid drifting hardware. Face panels are designed to protect subsystems from kick loads, as well as protect users from burns or stray radiation. Hand holds and foot holds are located to conveniently position the operator at control panels and viewing screens. Switch and valve covers help avoid inadvertent activations or deactivations.

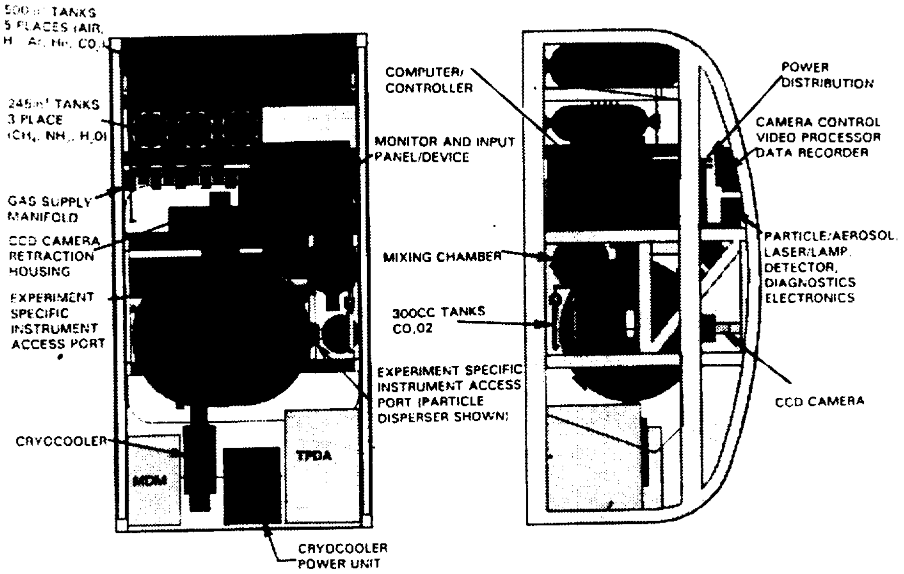
Some of the ISPR design definitions from SSP30000, include:

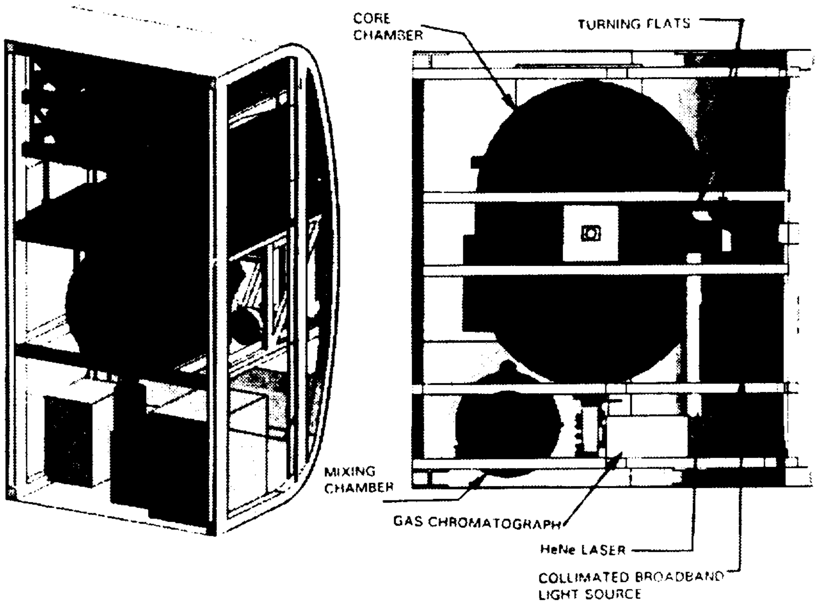
- 500 kg capacity
- upper and lower side access doors
- central rear access door
- RS 310 standard front bolt pattern
- EMI bonding/grounding provisions
- face plate for rack stability during shipping
- graphite epoxy posts
- interfaces for high & low temperature cooling water, nitrogen supply, vacuum system access, CO_2 fire suppressant, avionics air supply and intake, power, video monitor and control, time distribution, high data rate output, and payload monitoring.

4.4 Reference Design Drawings

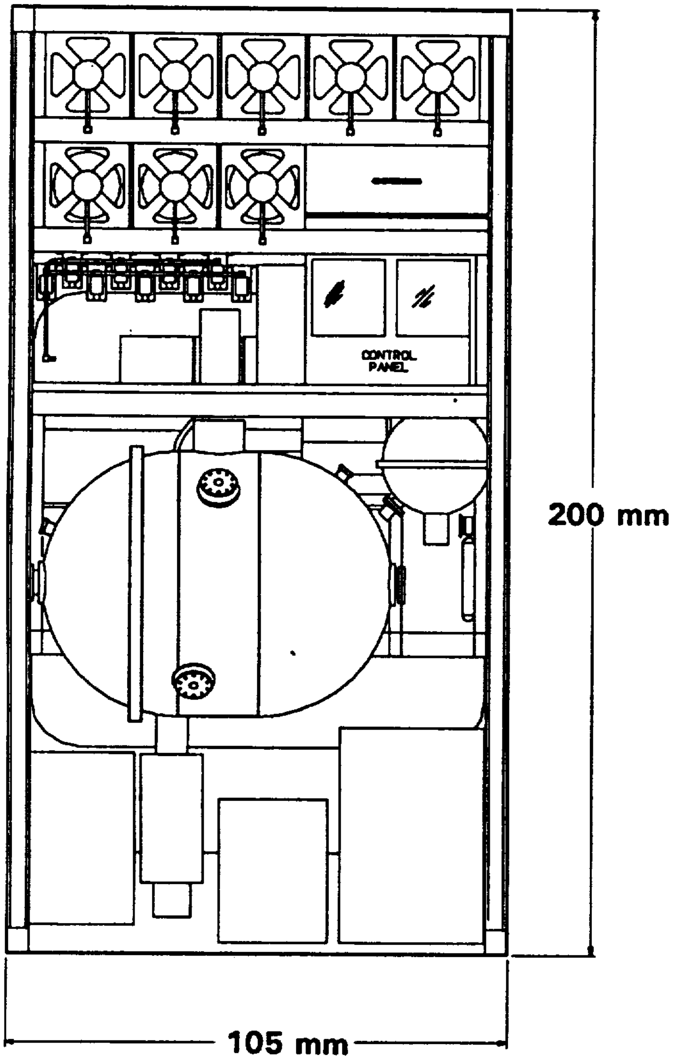
The following drawings were prepared in support of the GGSF Conceptual Design. They were generated as 3-dimensional solid models, and used to determine mass properties of the GGSF.

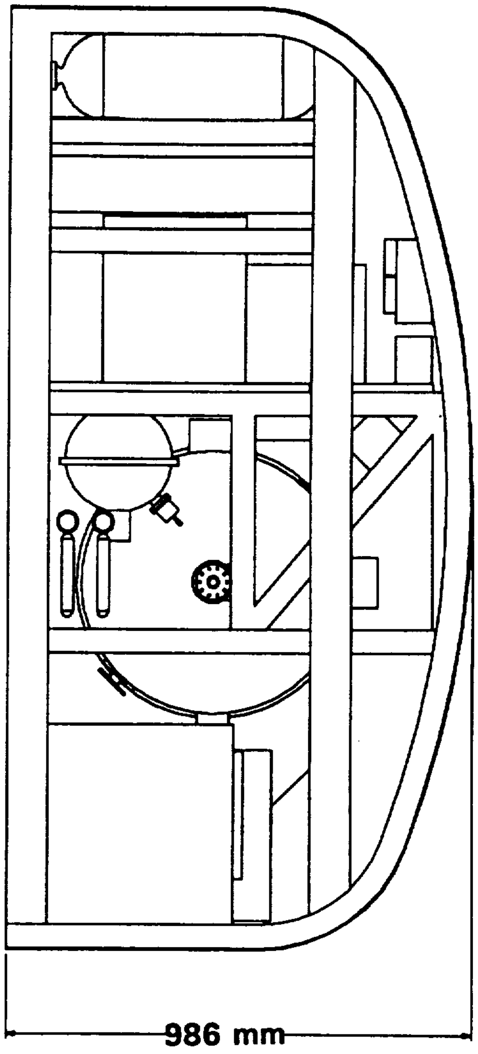
4.4.1 System 3-D -



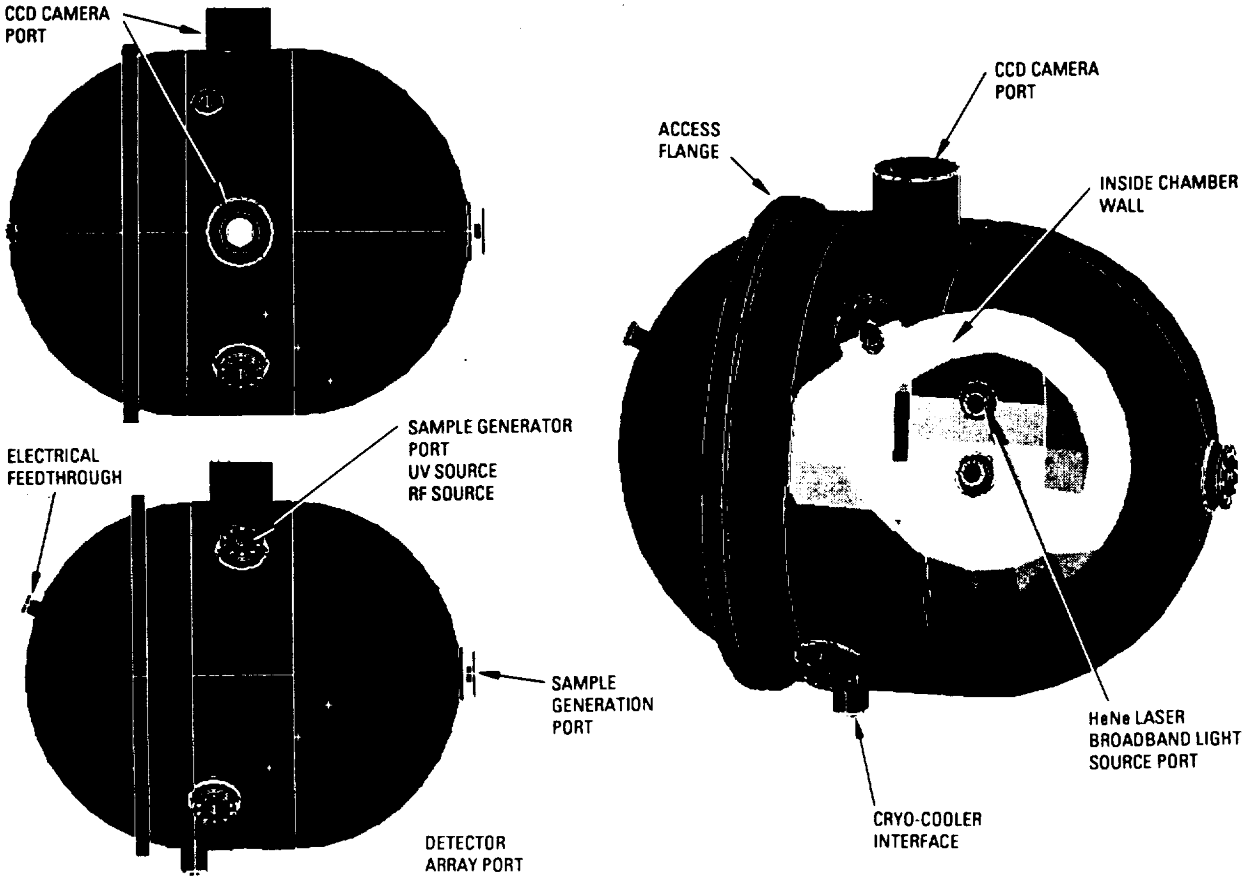


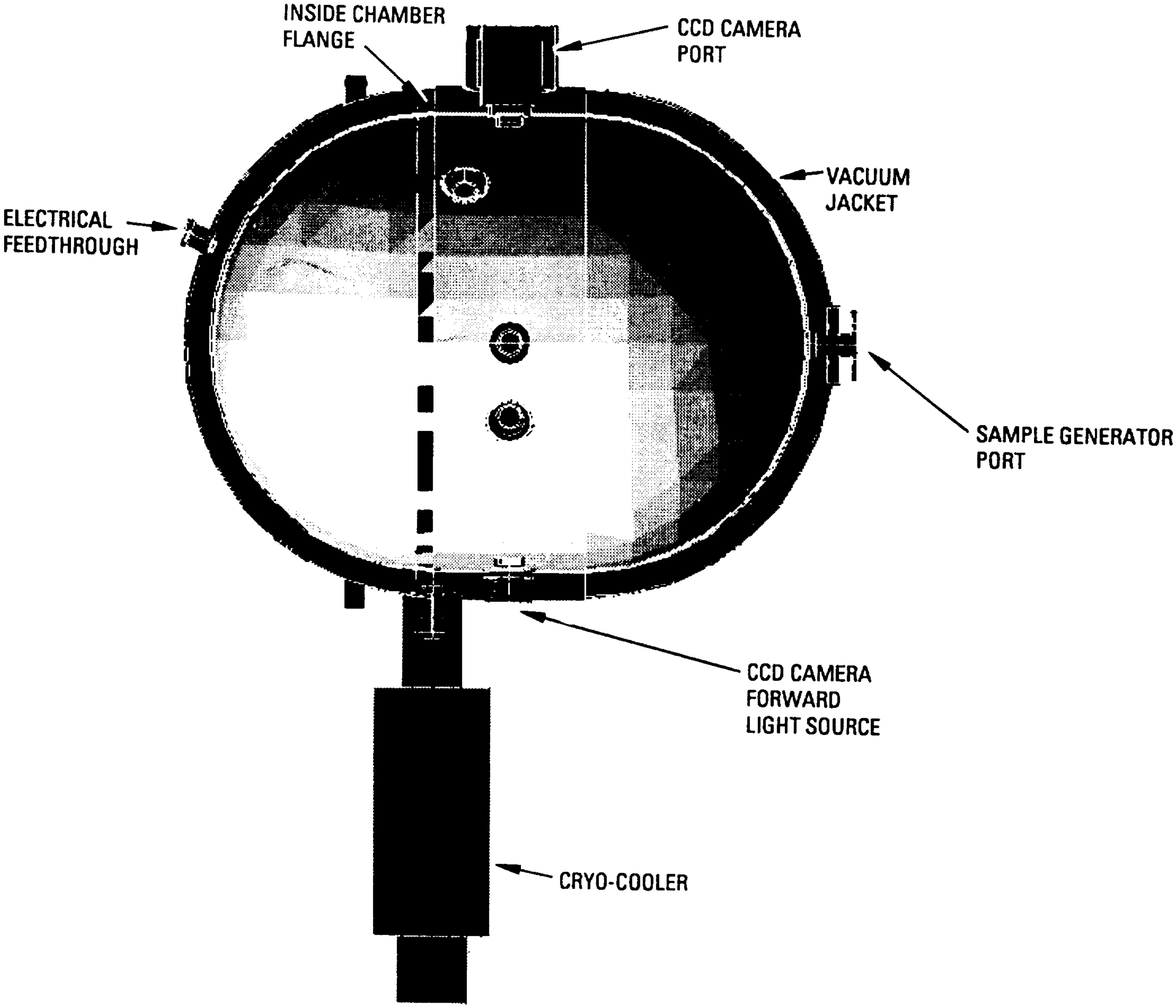
4.4.2 System 2-D -



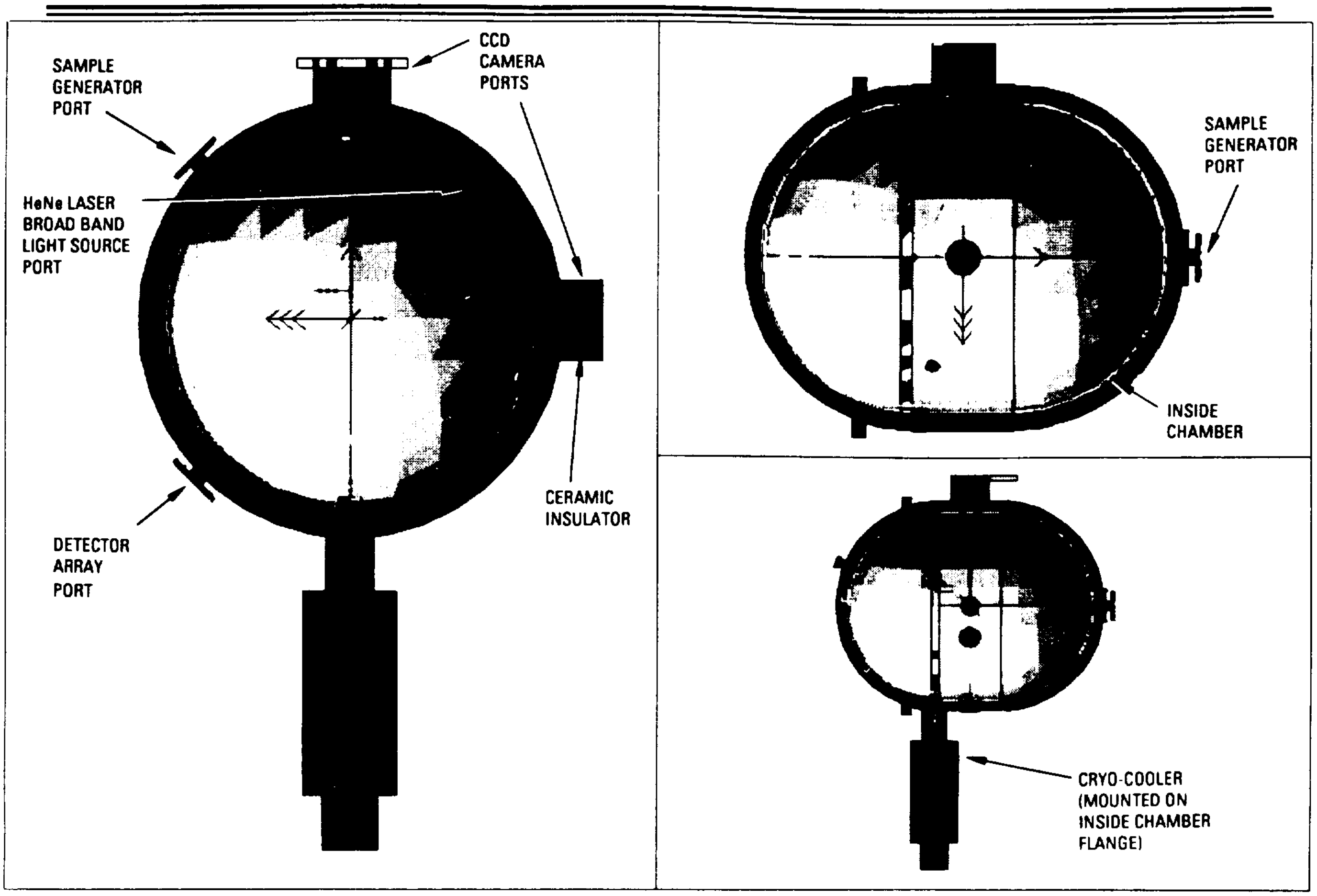


4.4.3 Core Chamber 3-D -

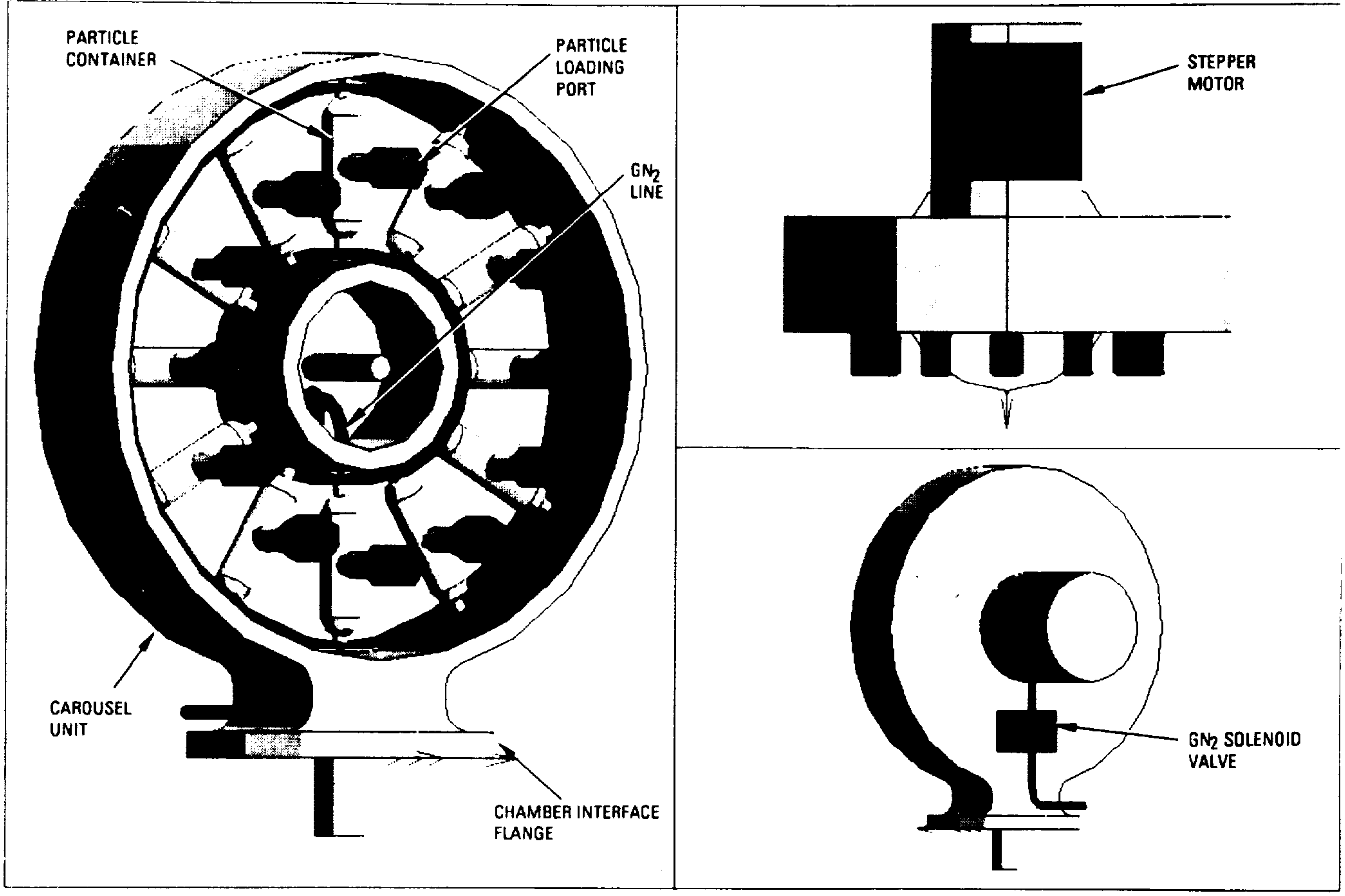



INSIDE CHAMBER FLANGE
CCD CAMERA PORT
VACUUM JACKET
ELECTRICAL FEEDTHROUGH
SAMPLE GENERATOR PORT
CCD CAMERA FORWARD LIGHT SOURCE
CRYO-COOLER

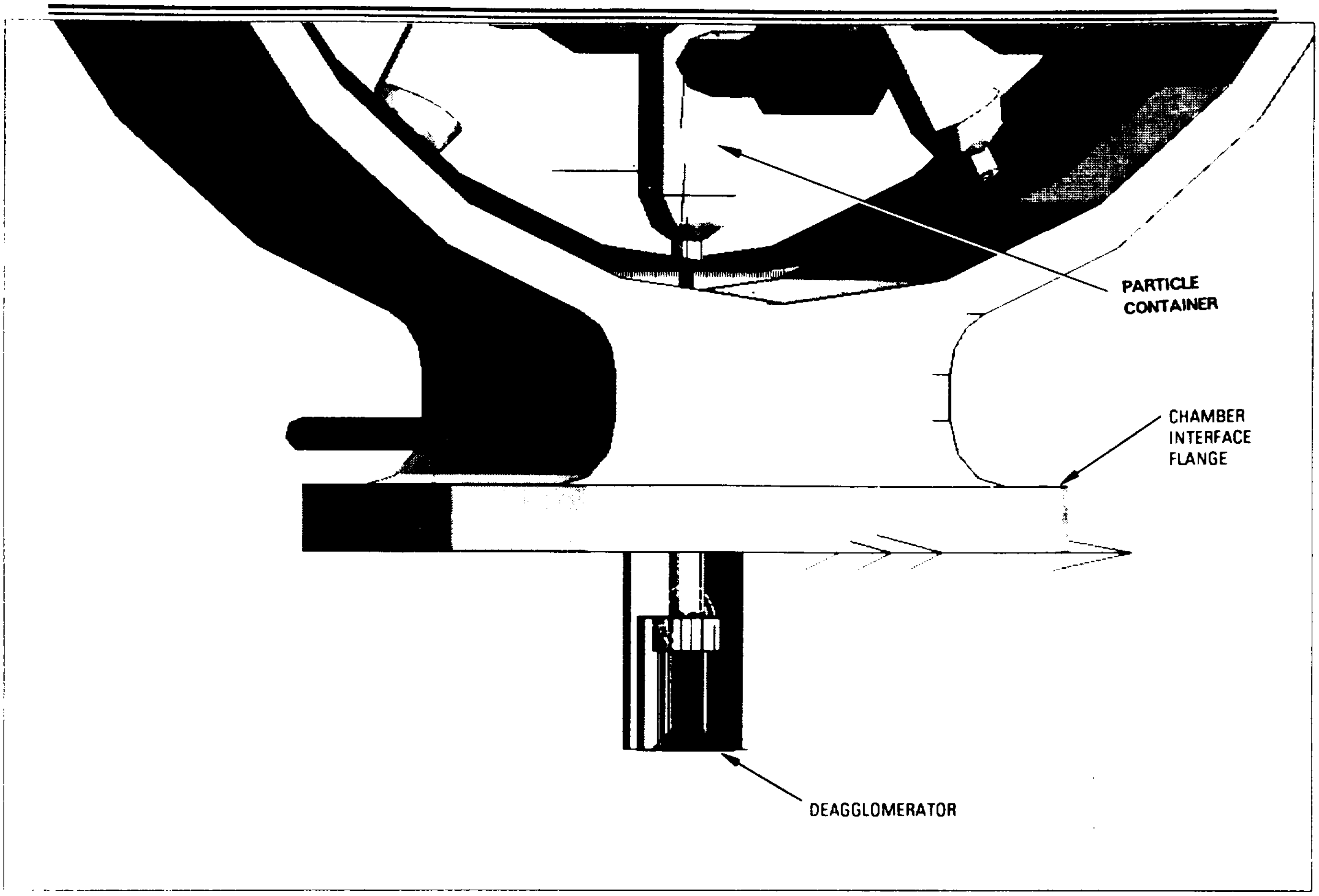
Core Chamber



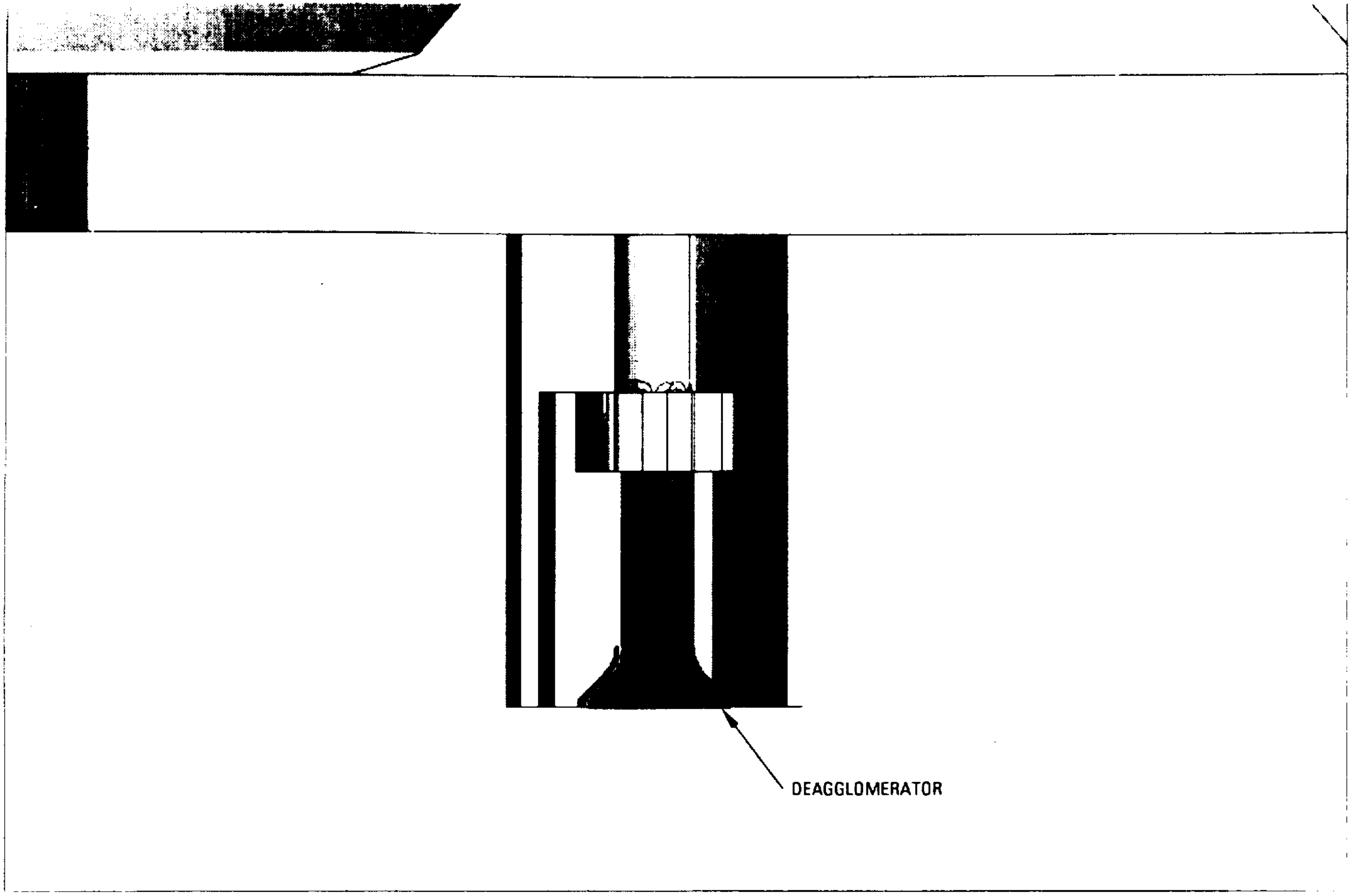
4.4.4 Particle Cloud Dispenser Concept -



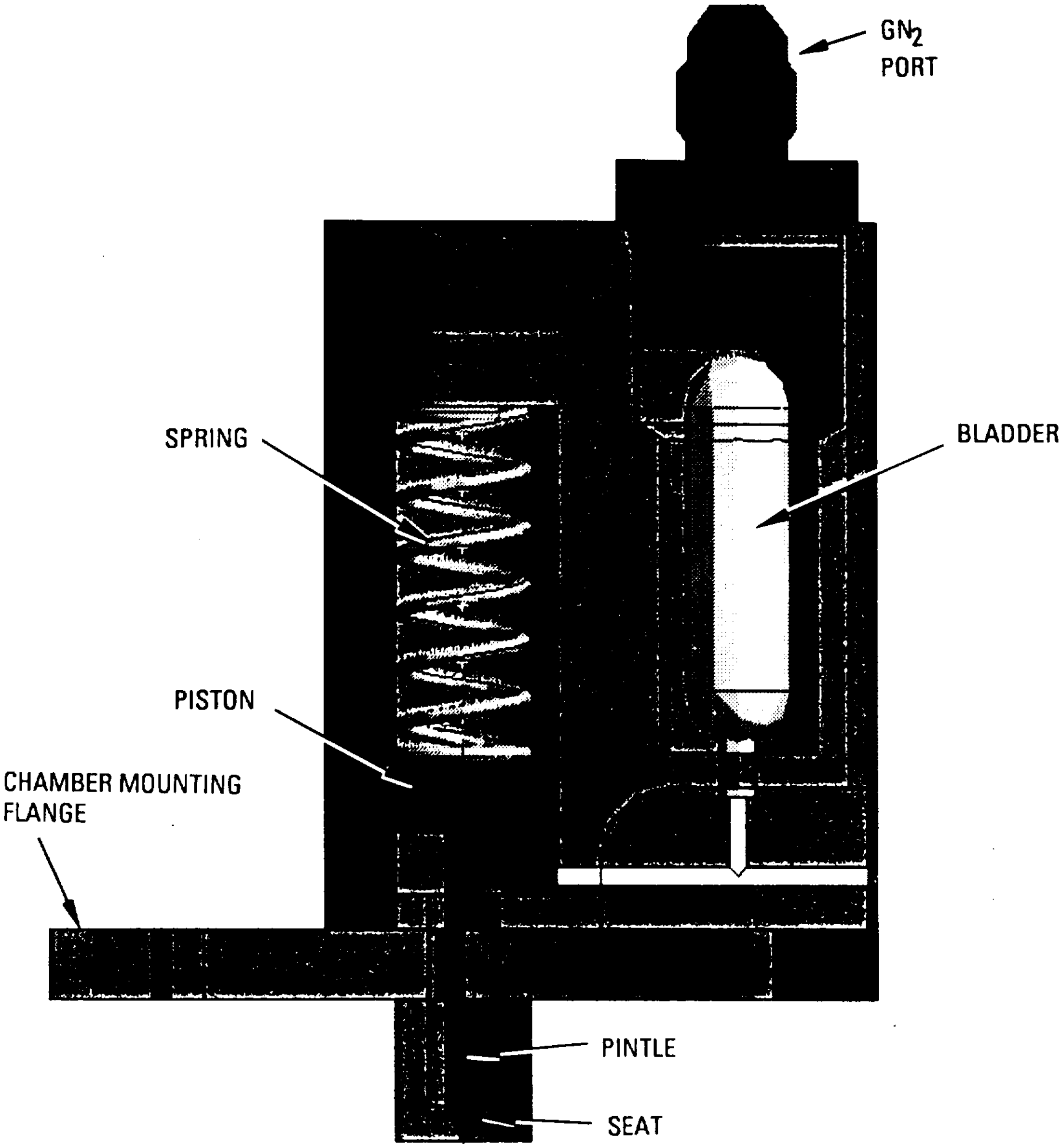
Particle Disperser



Particle Disperser



4.4.5 Liquid Aerosol Generator -



5 GGSF PROGRAM PLANNING

5.1 Schedule

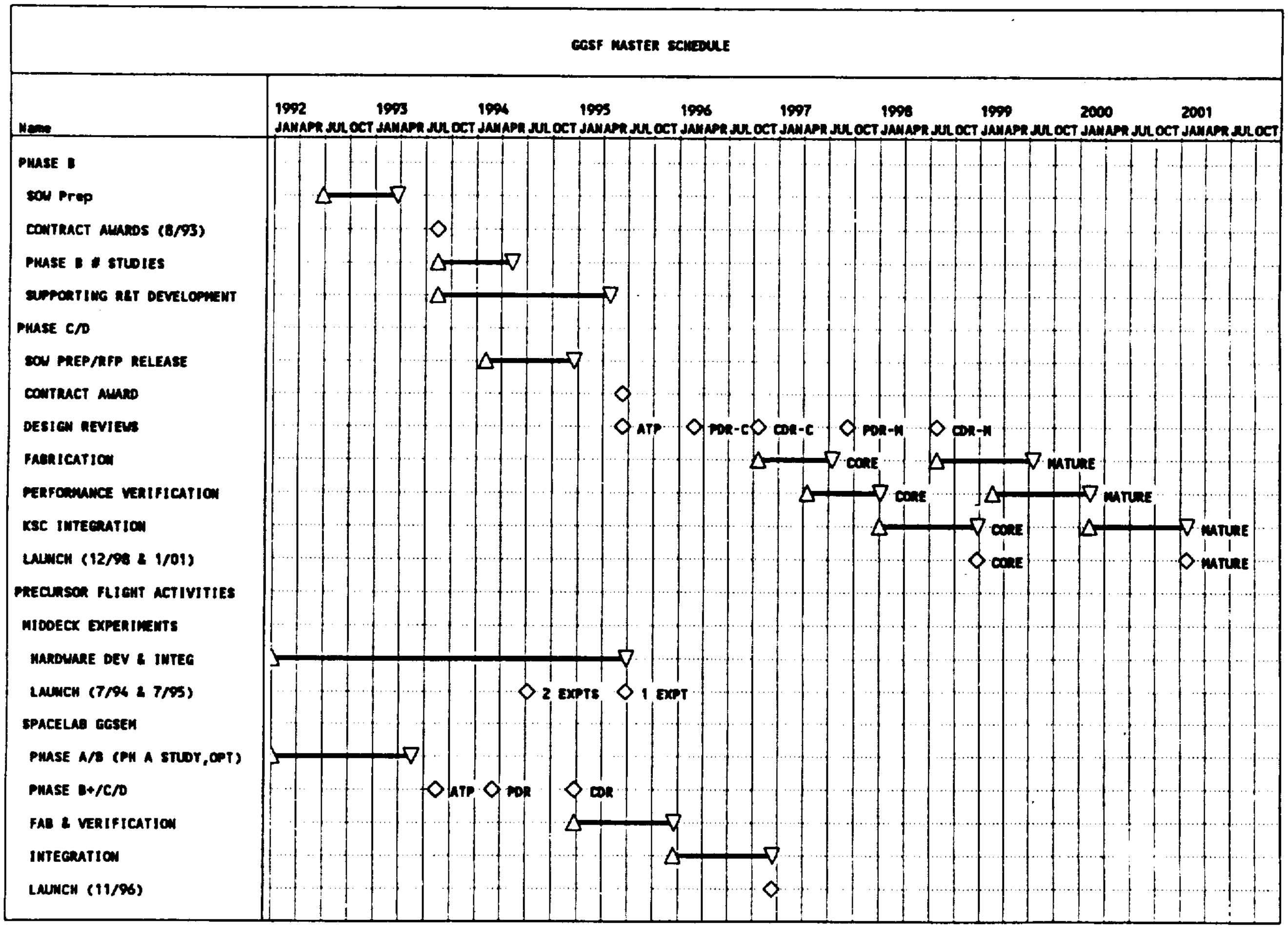


Figure 36 - GGSF Development Schedule.

5.2 Hardware Work Breakdown Structure

GGSF Assembly

- 1 chamber subsystem
    - 1 chamber-core
        - 1 chamber
        - 5 window assembly
        - 1 electrical feed-through
        - 1 cryocooler pump
    - 1 chamber-cryo
        - 1 chamber
        - 5 window assemblies
        - 1 electrical feed-through
        - 1 cryocooler pump
    - 1 chamber-vacuum
        - 1 chamber
        - 5 window assemblies
        - 1 electrical feed-through
        - 1 turbo-molecular vac pump
        - 1 cryocooler pump
    - 1 chamber-high temp
        - 1 chamber
        - 5 window assemblies
        - 1 electrical feed-through

- 1 electronics subsystem
    - 1 control system & data acquisition
    - 1 valve & heater controller
    - 1 cryocooler power unit
    - 1 experiment specific electronics
    - 1 modulator/demodulator unit (MDM)
    - 1 power conditioning & distribution
    - 1 rack power distribution assembly
    - 2 video display assembly
    - 1 video processor
    - 1 data recorder
- 1 gas handling subsystem
    - 1 mixing-chamber
    - 1 gas mixing equip
    - 1 sample removal system
    - 4 canister
    - 4 filter
    - 1 manifold & valves

    - 1 gas scrubbing unit
    - 1 large particle filter
    - 1 small particle filter
    - 1 absorbent scrubber
    - 1 catalytic scrubber
    - 1 Gas Fill System
    - 11 solenoid
    - 1 gas storage
    - 3 tank 8200 cc
    - 5 tank 4000 cc
    - 10 valve/regulator
    - 1 plumbing assorted
- 1 rack subsystem
    - 1 structure graphite/cover
    - 1 structure miscellaneous
    - 2 camera retraction assembly
- 1 sample generator subsystem
    - 1 soot generator
    - 1 single particle generator
    - 1 single droplet generator
    - 1 metal vapor generator
    - 1 uv photolysis source
    - 1 particle cloud generator
    - 1 large droplet cloud generator
    - 1 small droplet cloud generator
    - 1 rf source
    - 1 storage drawer
- 1 diagnostics subsystem
    - 2 ccd camera
    - 3 detector ring assembly
    - 1 IR detector array
    - 1 vis detector array
    - 1 off-line diagnostics
    - 1 environmental sensors
    - 1 humidity sensor
    - 2 resistance thermal detector
    - 4 thermocouple
    - 1 ionization pressure gage
    - 1 piezo pressure gage
    - 1 SAMS gravity sensor system
    - 1 gas chromatograph
    - 1 HeNe laser & power supply
    - 1 miscellaneous optics
    - 1 broad band light source

        - 1 white light
        - 1 filter wheel
- 1 positioning subsystem
    - 1 acoustic positioner
    - 1 electrostatic positioner
- 1 GSE hardware
- 1 SW GSE software
- 1 SW flight software-remote
- 1 SW flight software-manned

5.3 COST ANALYSIS

5.3.1 Summary - An estimate of the cost of developing the GGSF for Space Station has been performed using the PRICE-H, Expert-H, and COCOMO software packages. The estimated total costs (in April, 1992 dollars) are $47,270,000 for the Core Facility (limited capability) scheduled for launch in 1998, and $80,116,000 for the Mature Facility scheduled for operation in 2002. As requested, these costs are based on a platform number of 2.3. These numbers do not include G&A or profit, presumably due to the variation of rates and applications between different companies and contracts. This will increase the cost to the government approximately 30-35 percent. Cost estimates by PRICE-H are generally accepted to be accurate within 5-20 percent. The detailed costs are described in a separate document provided to NASA.

5.3.2 Details of the Estimate - An estimate of the cost of the GGSF development has been generated. The hardware cost estimate was performed using PRICE-H, a General Electric software package intended for this type of project. The software cost estimate was generated on COCOMO.

The PRICE-H software determines the cost of a hardware development task based on the weight of an item, and several complexity factors associated with that item. The estimate can be performed at any level of assembly, subassembly, or component, but the accuracy should improve at lower levels, as small assembly or component complexities are typically more accurate than an overall system complexity. The cost of an assembly includes the design, drafting, safety engineering, reliability engineering, design reviews, paperwork costs, meeting support, development testing, and proto-flight hardware fabrication, assembly, and test. These estimates do not include G&A or profit.

The platform number represents the type of platform that the hardware will be operated on, with standard selections including manned-space-based, which is applicable to the GGSF. The multiplication value associated with this category is typically 2.5, but for this estimate, has been reduced to 2.3 to reflect the customer request of consistency with SSF standards.

The complexity factors were determined with the assistance of the Expert-H software package, developed to provide standardization in the development of complexity factors. The output of this software is an input file for PRICE-H. The methodology for determining the cost consists of first determining the weight of mechanical components and electronic components in an assembly, and then assigning complexity factors for items such as engineering complexity, manufacturing complexity (mechanical and electrical), the amount of new design as opposed to existing hardware, the amount of repeated design, and integration complexity.

The PRICE-H software also accounts for affects caused by schedule. A very tight schedule (as estimated by the software) as well as a very stretched out schedule will increase the cost of the facility. The schedule used for this estimate was January, 1994 through June, 1996 for design, fabrication, and subsystem assembly, and July, 1996 through October, 1997 for system integration and test. A sensitivity analyses on schedule was performed and felt, and my feeling is that this is adequate for development of this facility.

The assumptions used to transition from the Core Facility to the Mature Facility are:

- increase from two core chamber to an additional cryo-chamber, high vacuum chamber, and high temperature chamber, along with 2 additional cryocoolers, and a turbomolecular vacuum pump.
- add a mixing chamber for pre-mixing and conditioning standard facility gases.
- increase from 3 particle generators to a full line of 9 generators.
- increase from a partial set of off-line diagnostics to a full set.
- add acoustic and electrostatic particle positioners.
- upgrade control electronics and software from pre-programmed and earth-controlled, to fully man-rated station operation.

The cost estimates also include spares. The following were considered important: an extra core chamber (total of 2) for allowing preparation of chambers on the ground, and shipment to station, while one on station is operating; a sample removal system which will be subject to damage by particles or residues during atmosphere exchange; gas storage system allowing refill and checkout of the system on earth, while one on station is operating; storage drawer to transport generators and samples to and from station in a shuttle middeck locker.

Expendable materials were not included in the estimate but gases, filters, and sample collectors will require periodic replacement.

6 SUPPORTING RESEARCH AND TECHNOLOGY NEEDS

The GGSF program could benefit from developments in various technology as summarized below. Some of these technologies are of interest to other programs and an additional small investment in those programs could provide a large pay-off. In other cases, specific investment in technology development by the GGSF program may be required. The selection of technologies to develop under the GGSF program should be pursued to maximize the benefits. Since funding constraints will limit the number of technology projects, the final selection should be undertaken with direct considerations of which are the most likely candidate experiments for early flight. The following is a list of technologies that support the GGSF program but require additional research and technology development in order to meet the specific constraints and requirements of the facility.

Cryocooler technology:
There are various refrigeration techniques that can provide the required amount of heat removal capacity at the desired 4K or required 10K temperatures of the GGSF experiments. The problem with these techniques is that they use heavy compressors, power supplies, and often operate on 220 to 440 volts AC, 3-phase circuits. An assessment should be undertaken of the various refrigeration technologies and the potential for reducing the size, weight and the power requirements. The technology for these devices is currently advancing rapidly in support of space based sensors. TRW has a long life, space-based cooler which falls into this category, but the current technology would require several cooling stages to reach the 4-10K temperature regime. GGSF will be able to take advantage of the state of the art for these coolers when the GGSF design is under way.

Particle measurement technology:
Particle counting and sizing technology is not easily applied to the GGSF requirements. The various commercial counters require a relatively high flow rate and a long measurement period in order to count and size particles as they pass through the measurement zone. These operating conditions are often incompatible with the GGSF available sample material, zero motion, and low pressure environments in the chamber. A useful effort in this area would include a miniaturization of the instruments and a reduction in the flow requirement and measurement time. Implementation of a scanning technique in place of moving the particles may be a solution, but has not been proven.

Sample generation -- Solid cloud Dispersion:
Solid cloud dispersion and deagglomeration techniques should be tested under conditions similar to those required by the experiment. This includes chamber size, pressure and temperature range, particle materials and size distribution, amount of powder, carrier gas type (if any allowed), etc. The technique must be tested in terms of the overall dispersion uniformity through the chamber, deagglomeration (if that is an issue), and preferably in a micro-gravity environment.

Sample generation -- aerosol generation:
The various aerosol generation techniques have distinct operating regimes in terms of droplet size distribution, uniformity, size range, etc. In most cases the technique does not work well outside the

range of specified parameters. In many cases a complete characterization of the technique and the operating limits are not well quantified in the literature. It is important therefore, to test the specific techniques with the required fluids, under conditions similar to those required by the experiment. This includes chamber size, pressure and temperature range, liquid composition, quantity of liquid, carrier gas type (if any allowed), etc. The technique must be tested in terms of the overall dispersion uniformity through the chamber, and preferably in micro-gravity environment.

Sample Retrieval and Manipulation:
A method or methods for sampling from a low-pressure chamber should be developed. The process of flowing gas through the chamber and "sweeping" particles out will end the experiment in some cases, by the intrusion of a gas. Robotic retrieval or impact methods should be investigated. Other methods of particle manipulation should be investigated as well. Manipulation without destruction of the particles is identified as a difficult task, as some of the particles are very fragile. These may lend themselves to methods such as light, acoustic, or electrostatic manipulation, all of which may have damaging affects on the particles, or may have other requirements not suitable to an experiment (such as gas in the chamber). Some dedicated research into this area should identify solutions and prove them out in a zero-g environment.

7 FINAL RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The GGSF Conceptual Design meets the requirements of most of the experiments currently planned. The facility also maintains the flexibility for addition of future experiments that can function within the facility as it is, or with the addition or exchange of facility hardware. The design phase A is intended to accommodate future technology upgrades that can enhance the usefulness as the science progresses.

There are, however several areas which still require further definition. The current design definition is limited by the undefined or over-ambitious science requirements. For example, diagnostic requirements are not adequately specified at this time to design the corresponding subsystem. The desired duration for experiments in a hard vacuum is significantly larger than the limits to settling allowed by gravity, yet levitation methods that won't disrupt the experiment are not currently known.

A better understanding of the science goals by the facility developer, combined with an increased knowledge of physical limitations for difficult requirements by the experimenter will result in a convergence of "real" requirements, an extremely useful and beneficial result for GGSF. This, of course, requires a close bond between the multitude of experimenters and the facility developer which can be achieved through conferences which include interested parties that are willing to participate and work towards accomplishing the GGSF goals.

C-2

8 References

1. NASA CR177606: Phase A Final Report, Volume I, Stage 1 - Facility Definition Studies, November, 1992.
2. NSTS 1700.7B - Safety Policy and Requirements, January, 1989
3. SSP 30000, Revision G - Space Station Program Definition and Requirements, June, 1991.
4. SSP 30261 - Data Management System Architectural Control Document, September, 1991
5. Handout from WP01 Rack Technical Information Meeting, July 17, 1991.

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13. ABSTRACT ***(Maximum 200 words)***

This document is Volume II of the Final Report for the Phase A Study of the Gas-Grain Simulation Facility (CGSF), and presents the GGSF Conceptual Design. It is a follow-on to the Volume I Facility Definition Study, NASA report CR177606. This report has been prepared under contract number NAS2-13408 for the NASA Ames Research Center.

This report delineates the development of a conceptual design for a Space Station Freedom (SSF) facility that will be used for investigating particle interactions in varying environments, including various gas mixtures, pressures, and temperatures. It's not possible to study these experiments on earth due to the long reaction times associated with this type of phenomena, hence the need for extended periods of micro-gravity. The particles types will vary in composition (solids and liquids), sizes (from submicrons to centimeters), and concentrations (from single particles to 10^{10} per cubic centimeter).

The results of the experiments pursued in the GGSF will benefit a variety of scientific inquiries. These investigations span such diverse topics as the formation of planets and planetary rings, cloud and haze processes in planetary atmospheres, the composition and structure of astrophysical objects, and the viability of airborne microbes (e.g., in a manned spacecraft).

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