NASA Contractor Report 177606

Gas-Grain Simulation Facility (GGSF) Volume 1 Stage 1 Facility Definition Studies

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ACRONYMS

μ-g	micro gravity
A/D	analog-to-digital
AC	alternating current
ACPL	Atmospheric Cloud Physics Laboratory
AI	artificial intelligence
ANN	artificial neural network
AO	announcement of opportunity
ARC	Ames Research Center
C&DH	command and data handling
c.g.	center of gravity
CCD	charge coupled device
CNC	condensation nuclei counter
CPU	central processing unit
CRT	cathode ray tube
D/A	digital-to-analog
DC	direct current
DCE	Droplet Combustion Experiment
DDM	Drop Dynamics Module
DMS	data management system
DPM	Drop Physics Module
EIA	Electronics Industry Association
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ESA	European Space Agency
FDDI	fiber data distribution interface
FES	Fluid Experiment System
FOV	field of view
FTIR	Fourier transform infrared
GC	gas chromatograph
GGSEM	Gas-Grain Simulation Experiment Module
GGSF	Gas-Grain Simulation Facility
GSFC	Goddard Space Flight Center
HAC	Hughes Aircraft Corporation
HPLC	high pressure liquid chromatography

INS	integrated nitrogen subsystem
IR	infrared
IRD	interface requirements document
ISPR	international standard payload rack
JANNAF	joint Army, Navy, NASA, Air-Force
JPL	Jet Propulsion Labs
JSC	Johnson Space Center
JT	Joule-Thompson
L.H.S.	left-hand-side
LeRC	Lewis Research Center
LSE	laboratory support equipment
LWIR	long wave infrared
MCPF	Modular Containerless Processing Facility
MDM	modulator demodulator
MFP	mean free path
MLI	multilayered insulation
MMAG	Martin Marietta Astronautics Group
MS	Mass spectrometer
MSFC	Marshall Space Flight Center
MSU	mass storage unit
MTBF	mean time between failure
MTC	Man Tended Configuration
MWIR	midwave infrared
NA	not applicable
NASA	National Aeronautics and Space Administration
NIR	near infrared
NRS	no requirement specified
NS	not specified
OMA	optical multichannel analyzer
OPC	optical particle counter
PAH	polyaromatic hydrocarbons
PDR	preliminary design review
PDS	payload development system
PI	principal investigator
PMC	Permanently Manned Configuration
PMS	particle measuring system

RAL	Rutherford-Appleton Labs
RF	radio frequency
RFP	request for proposal
RH	relative humidity
RPM	revolutions per minute
RTD	resistance thermometer device
S&T	science and technical
SAMS	space acceleration measurement system
SCSI	small computer system interface
SEM	scanning electron microscope
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
STP	standard temperature and pressure
SWG	science working group
TBD	to be determined
TC	thermocouple
UV	ultraviolet
VCR	video cassette recorder
VES	vacuum exhaust subsystem
VGS	vapor crystal growth system
VIS	visible
VOAG	vibrating orifice aerosol generator
VRS	vacuum resources subsystem
VUV	vacuum ultraviolet

1 BACKGROUND, INTRODUCTION, AND SUMMARY

1.1 Background

The Gas-Grain Simulation Facility (GGSF) will be developed to provide a microgravity (μ-g) laboratory in support of the exobiology community especially in the areas of small particles and gas-grain interaction. The GGSF is a facility-type payload to be included in the Space Station Freedom (SSF). The project is under the auspices and management of the Solar System Exploration Branch at NASA Ames Research Center (ARC).

The GGSF is a multidisciplinary facility that will accommodate several classes of experiments, including exobiology, planetary science, atmospheric science, and astrophysics. The physical mechanisms envisioned to be investigated include crystal growth, aggregation, nucleation, coagulation, condensation, collisions, fractal growth, cycles of freezing and evaporation, scavenging, longevity of bacteria, and more. This diverse set of experiments was suggested as the results of the workshop conducted by NASA ARC in 1987 and published as a conference report[1]. The list of experiments suggested at the workshop and the principal experimenters is given in Table 1. This workshop followed a previously held meeting on the subject, also conducted by NASA ARC, in which possible experiments of interest for various disciplines were discussed.[2]

TRW performed a Phase A study that included analyses of the science and technical (S&T) requirements, the development of facility functional requirements, and a conceptual design of the facility. This report summarizes the work that was performed under Stage 1 of the Phase A study and the results to date. In this stage, facility definition studies were conducted in sufficient detail to establish the technical feasibility of the candidate strawman experiments. The studies identified technical difficulties, identified required facility subsystems, surveyed existing technology for the subsystems, identified required supporting research and technology studies and established preliminary facility weight, volume, power consumption, data systems, interface definition, and crew time requirements. These requirements were **derived** on the basis of the 20 strawman experiment concepts which were generated at the workshop (plus another experiment added during the Phase A study), and the SSF accommodations.

The following is a brief summary of the key activities conducted under the Stage 1 study:

- S&T requirements were reviewed, analyzed, and consolidated into various categories. Additional needed data and clarifications were identified and reviewed with the NASA project science team and the experimenters, and a database was prepared in which the updated requirements were listed.

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[1] Gas-Grain Simulation Facility: Fundamental Studies of Particle Formation and Interactions, Vol. 1 and 2. Edited by G. Fogleman, J.L. Huntington, D.E. Schwartz, and M.L. Fonda. Proceedings of a workshop held at NASA Ames Research Center. NASA Conference Publication 10026, 1989.

[2] Microgravity Particle Research on the Space Station. Edited by S.W. Squyres, C.P. McKay, and D.E. Schwartz. Proceedings of a workshop. NASA Conference Publication 2496, 1987.

Table 1. Strawman Experiments List from the 1987 GGSF Workshop
(Experiment 21 was added at a later date)

Exp No.	Experiment Title	Contact
1	Low-Velocity Collisions Between Fragile Aggregates	S.J. Weidenschilling
2	Low-Energy Grain Interaction/Solid-Surface Tension	W.R. Thompson
3	Cloud Forming Experiment	J. Hudson
4	Planetary Ring Particle Dynamics	S. Squyres
5	Aggregation of Fine Geological Particulates in Planetary Atmospheres	J. R. Marshall
6	Condensation of Water on Carbonaceous Particles	C.F. Rogers
7	Optical Properties of Low-Temperature Cloud Crystals	S. Pope
8	Ice Scavenging and Aggregation: Optical and Thermal IR Absorption and Scattering Properties	J. Hallett
9	Synthesis of Tholins in Microgravity and Measurement of Their Optical Properties	B.N. Khare
10	Metallic Behavior of Aggregates	D. Podolski Traver
11	Investigation of Organic Compound Synthesis on Surfaces of Growing Particles	V. Oberbeck
12	Crystallization of Protein Crystal-Growth Inhibitors	J. Raymond
13	Dipolar Grain Coagulation and Orientation	F. Freund
14	Titan Atmospheric Aerosol Simulation	T. Scattergood
15	Surface Condensation and Annealing of Chondritic Dust	F. Rietmeijer
16	Studies of Fractal Particles	J. Nuth
17	Emission Properties of Particles and Clusters	L. Allamandola
18	Effect of Convection on Particle Deposition and Coagulation	W.K. Rhim
19	Growth and Reproduction of Microorganisms in a Nutrient Aerosol	S. Welch
20	Long-Term Survival of Human Microbiota in and on Aerosols	S. Welch
21	Study of Smoke Agglomerates	G. Mulholland

- The candidate experiments were classified and analyzed in depth to identify commonality in hardware requirements, and facility functional requirements were identified.
- The SSF, the U.S. Laboratory module, and the international standard payload rack (ISPR) accommodations, constraints, and interfaces were identified. The operational logistics of the SSF during man-tended configuration (MTC), and permanently manned configuration (PMC) were reviewed. This activity is based on the present status of the SSF, which is at the preliminary design review (PDR) level.
- Critical supporting research and technology areas that required further study were identified and recommendations of how such studies could be undertaken developed.
- Subsystems were identified, various approaches developed, and trade-offs conducted. Related space flight and μ-g programs and related technologies were reviewed and applicable lessons noted for incorporation into the GGSF program. Similarities with the

Modular Containerless Processing Facility (MCPF) were reviewed for potential areas in which technology could be shared.

- The initial NASA GGSF Feasibility Study[3] report was reviewed and issues that required further study were identified. Selected study issues were assessed and their impact on the technical feasibility of the GGSF assessed.
- GGSF requirements for use of artificial intelligence, expert systems, robotics, and other preliminary automation techniques were reviewed and potential levels of control suggested.
- Facility mission requirements, such as mass, volume, power, thermal, data, communications, and crew time requirements were assessed and possible experiment timelines for specific experiments or classes of experiments determined.
- Areas requiring further technology development were identified and specific experiment difficulties were listed.

The results of this study served as the basis for Stage 2 of the Phase A study in which a conceptual design and a reference design were performed. The results also served as a basis for a related study for a Gas-Grain Simulation Experiment Module (GGSEM), which is an apparatus intended to perform a subset of the GGSF experiments on board a low- Earth-orbiting platform. The purpose of this apparatus is to perform technology development and early science experiments. The GGSEM will meet the requirement of some experiments, or range of parameters of some experiments, that can be performed in a smaller, more limited capabilities apparatus and will provide a platform for the needed technology verification to reduce the GGSF program risk.

1.2 Summary of Key Study Conclusions and Results

A summary of the S&T requirements based on the strawman experiments is given in Table 2. The broad range of the S&T requirements specified for the GGSF, often incompatible with a single piece of equipment, resulted in the requirement that the GGSF be a modular facility with interchangeable subsystem assemblies. This facility will be composed of a flight rack in which a specific hardware configuration is installed for a family of experiments that can take advantage of the hardware commonality. In addition, the system will consist of an array of fully compatible, interchangeable assemblies that can be brought to SSF and installed in the flight rack to meet various other experiment requirements. The replaced assemblies can be returned to Earth for maintenance and/or upgrading as necessary. The interchangeable assemblies include various experiment chamber configurations, sample generators, diagnostics modules, experiment specific modules, electronic accessory plug-in units, and consumables such as gas cylinders. The initial flight configuration of the GGSF constitutes the **core facility**, while the full capability of the GGSF constitutes the **mature facility** configuration. The subsystems making up the GGSF core facility include all the maintenance and housekeeping subsystems such as command and control electronics, data acquisition, power distribution, waste management, and other interfaces. In addition, the core facility will include sufficient experiment subsystems to conduct a range of experiments. The core facility is planned for launch in the late 1990s.

[3] Miller, J.B., Clark, B.C. Feasibility Study for Gas-Grain Simulation Facility. NASA CR 177468; September, 1987

The major facility subsystems that have been identified include: chambers, sample generation and handling, diagnostics, gas storage and mixing, waste management, sample collection and storage, electrical power, command and data handling, environmental control, and structure. An overall facility block diagram with interfaces is given in Figure 1 and a summary of the subsystem functions and requirements, in Table 3. The table summarizes the requirements (discussed in the following sections of this Volume 1 report) from which the functions were **derived**, and identifies possible design solutions to be examined in detail in Volume 2 of this report.

Table 2. Summary of Science and Technical Requirements

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, soots 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 particulates 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
Particulates 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 MTC

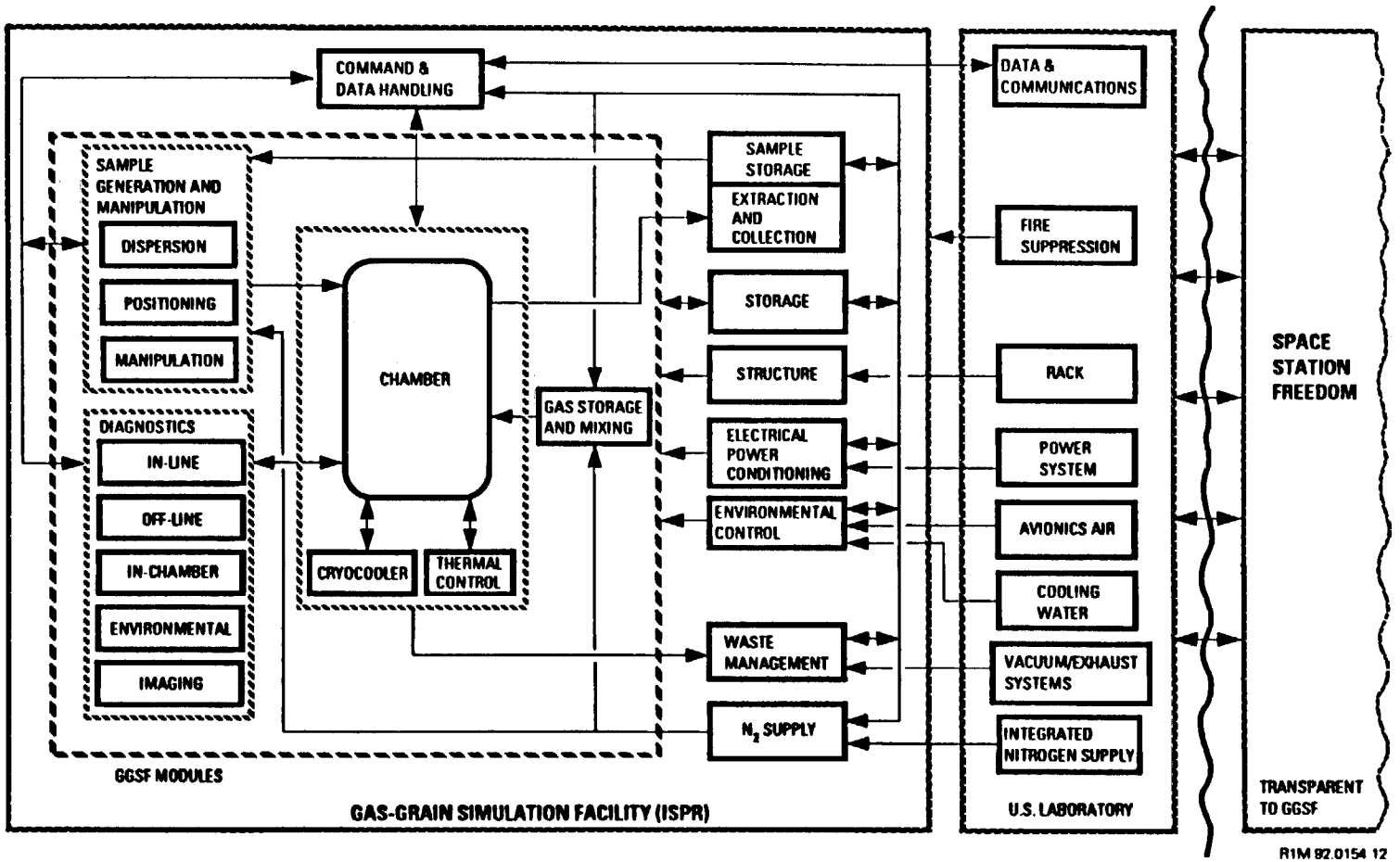


Figure 1. GGSF Overall System Block Diagram

Table 3. GGSF Functions and Requirements Summary

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Facility System	•Provide a broad range of capabilities satisfying the S&T requirements	•SSF constraints: volume, mass, power, safety, astronaut interface, crew availability, operating logistics, costs, etc. •S&T requirements	•Modular facility design comprises permanent elements and interchangeable subsystems to provide full range of capabilities. Required interchangeable subsystems are stored in GGSF; replacements are ferried on service missions. Consumables onboard are replenished on each service flight.	•A subset of the mature facility
Chamber	•Provide working volume to conduct all experiments	•Size up to 1 m^3 •Cooling time (see temp. req.) •Gas volume requirements (see gas handling req.) •Particle sedimentation rate •Diffusion rate •Station facility rack volume	•Four chambers (only one onboard at a time): •(1)Large volume, 67 liters, for temp. range 150K to 400 K, pressure 10^{-6} to 1 bar •(2) Low temperature, 4.2 liters, for temp. range 60 to 400 K, pressure 10^{-6} to 3 bar •(3) High temperature, 8.2 liters, ambient to 1200 K, chamber, pressure 10^{-6} to 1 bar •(4) High vacuum, 4.2 liters, temp. range 60 to 400K, pressure 10^{-10} to 1 bar •Other special chambers may be accommodated •Chambers to have identical mechanical, electrical, and diagnostics interfaces	•All chambers to be designed •One chamber fabricated and integrated •Unused ports blanked off
	•Provide controlled temperature environment for experiment	•Temperature: from 10 (4 K desired) to 1200K •Thermal radiative and conductive loads •Cooling/heating time	•Cryo-cooler, min. 15 W at 60K •"Cold filters" on windows •Provide cooling by isentropic expansion over limited range when compatible with experiment req. •Three chambers (except high temperature) provide interface to cooler	•Large volume chamber; temp. 150 to 400 K •Cryo-cooler included •Cooling by expansion
	•Provide controlled pressure environment for experiment	•Pressure from high vacuum to 3 bars (11 bars TBD) •Chamber weight •Chamber size vs. pump-down time •High vacuum special considerations (seals, materials, etc.) •Available station vacuum vs. specific pump •Type of pumps required •Need to access interior of chamber	•10^{-6} (using station vacuum line) lower pressure limit on all chambers •Upper limit 1 bar for high temperature and high vacuum chambers •Upper limit 3 bars for low-temperature chamber •Integral vacuum pump for high-vacuum chamber	•High-volume chamber provided (10^{-6} to 1 bar)

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Chamber (cont.)	•Diagnostics	•See separate entry	•See separate entry	
	•Provide cleaning capability and access to the chamber interior	•Impact on vacuum seals •Impact on thermal insulation •SSF safety considerations •Cleaning concepts: purge, bake out, wash, solvents	•Provide an access port for cleaning •Cleaning capability via (1) N_2 purge, (2) low temp. (~400 K) bake; interior access not recommended in orbit. •Define cleanliness criteria and schedule experiments based on compatibility	•Same as mature facility
	•Provide access ports	•Diagnostics ports •Illumination •Sample insertion •Gas feed/vent lines •Insertion of experiment-specific hardware and diagnostics •Trade-off ports vs. heat loads, design complexity, cost	•Two camera ports •Two illumination ports •Two in-line diagnostics (entrance/exit) ports •Two sample generation port •Gas line (valved to fill/vent/GC) •Off-line diagnostic port •Sample removal port •Electrical power port •Electronic sensors and data port	•Same as mature facility

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Sample Generation and Manipulation	•Disperse solid particles into chamber •Aerosolize liquids and disperse into chamber •Vaporize metals and silicates into chamber •Generate and insert soot into chamber •Position single particle/droplet in chamber •Accelerate particles to affect collisions	•Type of sample material •Drop/particle size and size distribution •Number density •Pressure & temperature in chamber •Micro-g operation	•All sample generators interchangeable with all chambers and have common interfaces •During MTC, sample generators shall allow for repeated tests with similar or different samples •Sample generators shall be capable of repeated and automated operations •Solid particle disperser shall operate with particles of all sizes from submicron to millimeter •Solid particle disperser shall operate with minimum carrier gas •Liquid aerosols generator shall operate in the range 0.1 to 200 μm •Provide nebulizer for high number density, large liquid drops •Provide a liquid aerosol generator operating with no carrier gas •Provide a single-particle handling device (experiment-specific) •Provide soot generation by hydrocarbon fuel combustion •Provide electrical arc to vaporize metals and silicates •Provide UV source for photolysis •Provide RF source for haze formation	•Solid particle disperser as for mature facility •Liquid aerosols as for mature facility •UV and RF sources as for mature facility
	•Provide means for sample manipulation	•Positioning •Levitation •Interference with experiment sample •Cloud levitation impracticality •Complexity and useful range of systems (acoustic, electrostatic, aerodynamic, light, etc.)	•No cloud positioning •Large single particle position via mechanical systems (experiment-specific hardware) (TBD) •Collision control (TBD) •Electrodynamic levitation as an experiment-specific hardware •Other techniques also experiment-specific hardware (TBD)	•Not provided

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Diagnostics	•Provide diagnostics using in-line light scattering techniques for determination of cloud characteristics and optical properties of particulates	•Available techniques •Light sources selection •Detector types •Chamber windows number & size (see also impact on cooling req.) •Spectral and spatial (angular) resolution req. •Measurement flexibility	•Provide angular (and forward) scattering (Si response range [400-1000 nm]) angular resolution (TBD) deg (TBD linear array detectors) •Provide array of Si detectors for angular scattering •Provide in-line particle characterization via extinction measurements and/or diffraction •Provide spectral (VIS/NIR/MWIR ranges; Si and PbS) detection in forward direction only •Provide light polarization measurements capability •Provide a broad spectrum source (incandescent or discharge) 0.3 to 3.5 μm (power, type TBD) •Provide monochromator or a filter wheel (TBD) for source wavelength selection •Provide coherent source (e.g., HeNe laser, 0.5 mW) •Provide common light path for sources via adjustable mirrors (one source at a time)	•All core facility capabilities provided
	• Provide imaging capabilities	•Analog video •Digital imager •Frame rate (req. unspecified) •Data volume, rate •spatial resolution (req. unspecified)	•Provide 2 orthogonal CCD cameras •Provide analog/digital imaging data storage (TBD) •Frame rate: single frame to 100 fps •Spatial resolution (TBD) (no req. specified) •Provide white illumination source (front- or back-lighting TBD)	•All core facility capabilities provided
	•Provide off-line particle cloud characterization for submicron particles	•Off-line particle counter technologies •Chamber access needs •Interference with experiment •Sampling needs, flow rates, duration	•Provide access to chamber and interface to interchangeable off-line (remote) counters: e.g., • Optical particle counter (0.2 to 40 micron) • Condensation nuclei counter, size range (TBD) • Other possible counters (mobility analyzers, diffusion battery, etc.) (TBD) • Only one counter available on board (unless extra storage available)	•Access port blanked •No off-line counter onboard
	•Provide experiment Specific diagnostics capabilities	•e.g., FTIR	•Concept only; not designed now •Chamber windows to be replaced with IR transmitting windows (e.g., ZnSe) for FTIR •Interferometer interface with chamber	•Minimize experiment specific operations

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Diagnostics (cont)	•Provide environmental monitoring capabilities	•Pressure monitor •Temperature control •Gas composition monitor	•(TBD) temperature sensors shall be installed in each chamber to monitor wall and interior temperature •Chamber temperature shall be measured to ±(TBD) K •Slow-response pressure sensors shall be interfaced with each chamber to cover the range of operating pressures •Isolation valves for sensor protection shall be installed •The vacuum gauges shall have high (TBD) conductance interface to the chamber •Pressure and temperature shall be continuously monitored during the experiment •Gas chromatograph shall be connected in line with chamber and gas handling subsystem	•All core facility capabilities provided
	•Provide measurements of the g-level in three axes down to 10^{-6}g	•10^{-6} DC level •Station vs. direct facility data •Size, weight, power requirements	•The diagnostics subsystem shall provide a 3-axis accelerometer head mounted on chamber; electronics control (TBD) •The accelerometers shall be monitored and data collected by the control and data management subsystem	•Chamber designed to accommodate sensors •Availability of system (TBD)

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Gas Storage and Mixing	•Provide gas storage and control capability •Provide gas mixtures into chamber	•Pre-mixed bottled gases •On-board mixing •Mixing techniques •Gas volume requirements (chamber volume) •Number of experiments and repetitions •Experiment pressure •Size and weight of tanks •Replenishment logistics	•Major gases (O_2, Ar, He, CO_2, H_2, etc.) shall be supplied in large manifolded cylinders •Minor gases (NH_3, CO, CH_4, etc.) shall be provided in small cylinders •Special mixes shall be available in small manifolded cylinders •Air shall be made up with O_2 and Station GN_2 •Manifolded tank pallet shall be replaceable and provide gases for up to 180 days operation •Mixing chamber shall be used to prepare a mixture which is then fed to test chamber •Mechanical stirrer shall be provided in mixing chamber •Mixing chamber shall be filled by partial pressure; monitor pressure and temperature taking into account for gas compressibility factor •Mixture composition shall be verifiable by GC analysis	•Premixed gas cylinders shall be provided •Small corrections to premixed gases shall be made in experiment chamber
Waste Management	•Remove particles and toxic/corrosive gases from effluents •Provide storage for waste •Provide interface to the VRS and VES	•Clean-up of products and vent •Collection of all products in GGSF •Use Station waste vent (not enough info. available yet)	•The waste management shall provide in-line scrubber to remove gases (e.g., reactive charcoal, other as needed) and filter to remove particles •All cleaned gases are vented overboard through the VES/VRS •The removal efficiency shall meet the applicable SSF requirements •Operation of the waste management subsystem shall be timelined and controlled by the C&DH subsystem •The waste management shall be monitored by the command and data handling subsystem •All filter and scrubber canisters shall be replaceable onboard	•All capabilities available (scrubber compatible with experiments)

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Sample Collection & Storage	•Provide Sample collection capabilities	•Single particle removal •Removal of a cloud or ensemble of particles	•Provide access to chamber for removal of a single particle (e.g., crystal) •The sample removal subsystem shall have provisions for a single in-line filter and/or impactor or cascade impactor for the removal and classification of samples (TBD).	•System shall have an in-line filter for sample collection
	•Provide storage for sample materials preexperiment •Provide storage for post-experiment sample •Provide sample preservation capability as necessary	•Access into chamber •Nature of sample •Collection techniques •Maintain sample characteristics	•Sample generator shall be capable of storing sample material for (TBD) experiment repeats •Storage volume shall be allocated •Storage shall have (TBD) environmental control for sample preservation	•Same as mature facility
Hardware Storage	•Provide storage for experiment-specific and interchangeable hardware, and tools	•Available volume, mass •Logistics for performing experiments and repeats •Replenishment schedules	•(TBD)	•(TBD)
Electrical Power	•Provide power conditioning and distribution for the GGSF subsystems	•Station provided power at 120 Vdc •Instruments power requirements •Noise, EMI/EMC requirements	•Power conditioning shall be compatible with the SSF 120 Vdc input •Provide 8, 18, 28 Vdc and 115 Vac (power level each TBD) •Meet all EMI/EMC specifications (TBD) •EMI bonding/grounding shall be considered in the design of GGSF •Provide a total power level of 3.0 kW	•Full capability

Table 3. GGSF Functions and Requirements Summary (Continued)

Subsystem	Function	Major Drivers & Constraints	Mature Facility Requirements	Core Facility Requirements
Command and Data Handling (C&DH)	•Provide experiment control capabilities •Provide data acquisition and analysis capabilities •Provide interface with the SSF data management system •Provide capabilities for experiment automation •Continuously monitor the engineering state-of-health of GGSF	•Experiment control and monitoring needs •Data rate •Data transfer to Station and real-time downlink •Autonomous data storage capabilities •Automation, expert systems capabilities	•The C&DH shall constitute a modular microcomputer subsystem •The C&DH shall accommodate various I/O cards (e.g., A/D, D/A, video frame grabber, etc.) •The C&DH shall provide onboard data storage capacity of (TBD) Mbytes •Provide memory storage for application software for data processing •Provide programmed experiment control capability •The C&DH shall be capable of monitoring all experiment diagnostics •Provide I/O interface (CRT monitor, keyboard or touch-screen) •The C&DH hardware and software shall be compatible with expert system implementation •The C&DH shall include MIL-STD-1553 interface capability and shall allow for FDDI interface •The C&DH shall monitor GGSF health and provide automated safe shutdown in case necessary	•Full capability
Structure	•Provide GGSF support structure compatible with SSF U.S. module accommodations	•Mass, volume requirements	•One ISPR •Additional 1/2 rack for storage may be required	•One ISPR
Environmental Control	•Provide interface to the cooling water and avionics air for GGSF environmental control	•Cooling requirements	•The subsystem shall provide all the required cooling and thermal control for the electronics and instrumentation •The subsystem shall be controlled and monitored by the C&DH subsystem	•Full capability

The objective of the facility functions is to allow accommodation of the largest number of experiments. Similarities and conflicts between experiments were noted and their impact on the facility functions assessed. Ultimately, recommendations were made for functions which, based on the science, technology, and SSF accommodations, appear to maximize the facility utilization. Such recommendations imply some degree of prioritization. But the study made no deliberate attempt to prioritize the science which the GGSF will investigate. The concept of modularity was introduced to broaden the facility utilization and to accommodate conflicting needs that can not be satisfied by a single approach. In some cases this approach did not resolve all the issues and some experiment requirements (or only a range of the parameter-space) could not be met. Hence, the facility functional design may ultimately lead to the exclusion of certain experiments, class of experiments, or a portion of the parameter space. Conversely, the analysis may identify other μ-g facilities that are more appropriate for these experiments.

This document contains a significant amount of analyses and discussions of the technical feasibility of performing certain functions. The purpose of these discussions is to present the choices, the decision process, and the rationale that led to the decisions. This will help NASA and the science and engineering communities to crystallize their thoughts and ideas about what the GGSF should really be, and will lead to a GGSF that can better serve the intended community. Similarly, the discussion of the technical and engineering difficulties and the major design drivers may lead the experimenters to reconsider "difficult" requirements. Alleviating "difficult" requirements, when science is not compromised, can lead to a substantial simplification of the facility design and cost saving.

Other programs that are relevant to the GGSF or may share commonality in terms of hardware and technology development were reviewed. These programs are listed in Table 4, including the status of the program and the relevant elements. The various organizations involved (some of which are at TRW) were contacted and an attempt was made to extract as much information as possible and implement the lessons learned to this study.

Table 4. Programs Relevant to GGSF

Program	Development Status	Relevant Elements
Containerless Processing Module (CPM)	Rocket flight	Single particle deployment
Drop Physics Module (DPM)	Flown on SL-3	Acoustic levitation; particle/droplet deployment; facility configuration
Drop Dynamic Module (DDM)	Integrated, scheduled for USML-1	Same as DPM
Fluid Experiment System (FES)	Flown on SL-3	Thermally controlled cell; HeNe Laser 20 mW
Vapor Crystal Growth System (VGS)	Flown on SL-3	Microscope; video
Atmospheric Cloud Physics Laboratory (ACPL)	Through detailed design	Aerosol generator; 50-liter chamber; imaging (photography); temperature control
Droplet Combustion Experiment (DCE)	Engineering model	20-liter chamber; HeNe laser; multiple view ports, droplet injection; photography

The technology assessed is not always present-day space-flight technology. Projections for the technology status to the time GGSF will be built were made and the advantages of anticipated developments incorporated. This has particular relevance to the area of computer control, artificial intelligence (AI) systems, robotics, and imaging. Finally, experiment techniques and approaches requiring further development, testing, verification, and otherwise proof-of-principle were identified. This area has particular relevance to the overall subject of particulates technology in μ-g.

The major facility design drivers were identified to include:

- Very low temperatures (<40 K)
- High vacuum ($<10^{-6}$ bar)
- Large volume (> 100,000 cm^3)
- Chamber and window cleaning issues.

The facility concept that evolved in this study can meet the majority of the experiment requirements. Facility limitations can be classified into three major categories. Details of these limitations are analyzed and reviewed throughout the report; the most important ones are listed below.

1. Experiment duration
   - For experiments performed in vacuum, the sedimentation time for all particle sizes is of the order of 30 to 50 seconds, depending on the chamber size.
   - For experiments not conducted in vacuum, the very small particles (e.g., submicron) are lost to the chamber wall by diffusion in a relatively short time. The very large particles are also lost in a relatively short time by sedimentation.
2. SSF constraint
   - Restrictions on the use of cryogenic fluids on board the U.S. Module limit the practical low temperature that can be achieved with mechanical cryocoolers to about 40 K for a small chamber (about 4,000 cc), and about 150 to 200 K for a large chamber (about 65,000 cc). This issue has not been completely resolved during the study; both, constraints by the SSF program on the use of cryogenics and logistics constraints were considered. For the remainder of this study it was **assumed**, therefore, that cryogenics are not available for the GGSF. This issue should be re-addressed in a future study.
   - Very stringent requirements limit the overboard dumping of certain gases. Some of the requirements may even be incompatible with the impurity level of the SSF-supplied GN_2, creating the need to install a complex waste management system.
3. Present and anticipated technology limitations
   - Sample generation, introduction and distribution in the chamber when no carrier gas is acceptable, or when no initial velocity can be tolerated (e.g., in vacuum).
   - Diagnostics that require sample removal from the chamber when the chamber is in vacuum (e.g., very dilute samples or submicron particles that can not be diagnosed *in situ*).

In the process of developing the GGSF concept, it was noted that certain types of subsystems that are required by the facility will also be required by other users and facilities on board the SSF. These include the waste management subsystem, a modular payload computer subsystem, a 120 Vdc power conversion and distribution subsystem, instrument calibration services, etc. It

is noted that NASA could reduce the development cost of the user's facilities if such generic units compatible with the various SSF facilities were developed.

A major conclusion of this study is that particle/aerosol generation techniques and various aspects of their behavior in μ-g is crucial for GGSF and a technology development effort in these areas is essential. A preliminary effort to develop and test particle dispersion and aerosol generation techniques was conducted in parallel with these studies under the GGSEM program.

1.3 Study Ground Rules and Approach

All experiments were considered as representative experiments for their respective disciplines, and although the various experiments exhibit different levels of maturity they were all given similar weight. Some experiments' descriptions and requirements were supported by extensive past laboratory experience, while others have had a limited history of laboratory investigation. Lack of inputs was considered as an indication that more studies are required.

Nevertheless, in this Phase-A study level, the science data were primarily utilized to bound the facility requirements and set an upper/lower limit for the various experiment parameters. These experiments have not been selected for flight, yet, and there are no principal investigators (PIs) at this time. Another consideration is that the facility is scheduled to orbit Earth for over 10 years. As a result, new experiments and new requirements will emerge in the future. *The definition of the facility functional requirements must attempt to foresee such needs, to avoid too-specific a design to the present list of experiments, and to provide interfaces and room for growth.*

The process of deriving the mission and functional requirements, depicted schematically in Figure 2, included the following steps.

- Review and analysis of the experiments
- Categorizing the experiments
- Development of an experiment database that included quantitative and descriptive information regarding each experiment
- Review and update of the database with the principal experimenters and the NASA/ARC science team
- Development of "composite" experiment requirements
- Assessment of the appropriate SSF accommodations
- Assessment of the technology available to meet the science and technical requirements
- Identification of the functional facility requirements
- Relating the functional requirements to subsystems requirements.

In Stage 2 of this study a reference design was developed. The design related the hardware concept back to the experiments and the S&T requirements.

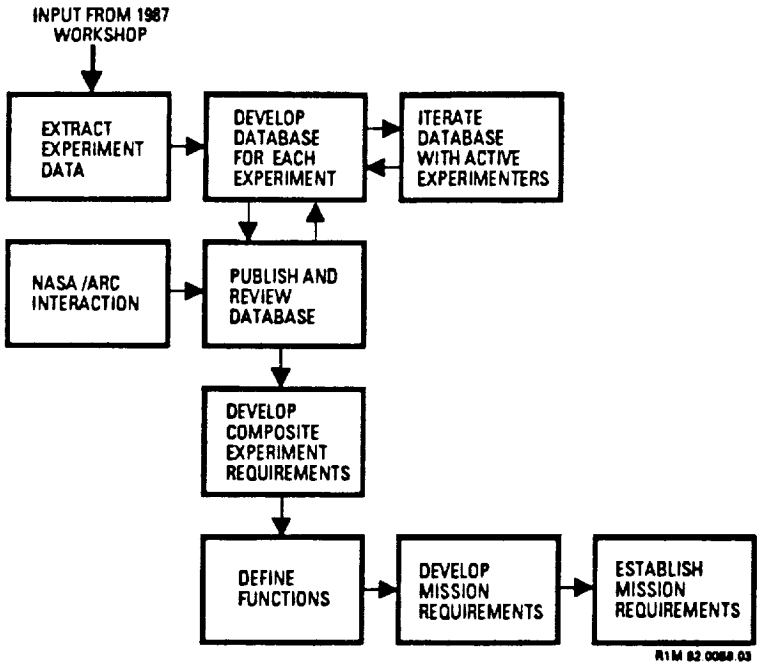


Figure 2. Requirements Flow Development for the GGSF

1.4 Report Organization

- In Section 2 the S&T requirements are listed and discussed. The discussion is limited to the interpretation of the S&T requirements, to the identification of potential issues with specific class of requirements, and identification of physical constraints. Issues requiring special attention are summarized.
- Section 3 briefly describes the SSF accommodations and constraints under which the GGSF will operate.
- The analyses, considerations, trade-offs, and possible technical approaches leading to the definition of the facility functions and requirements are found in Section 4. Critical issues and or lack of definition and requirements are *italicized* in this section.
- Sections 2 and 4 are organized in accordance with specific functions of the GGSF and the corresponding subsystems.
- Section 5 provides a brief discussion of the facility mission requirements.
- A conceptual facility design is reviewed in Volume II of this report.
- A cross-reference for the GGSF S&T requirements, functional requirements, and related discussions can be found in Table 5, which is organized by key GGSF subsystems as developed during the study.

Table 5. Cross-Reference and Functional Requirements by Major Subsystems

Subsystem	Function	S&T Req. Section	SSF/ISPR Accom-modations	Functional Requirements, & Related Analyses
Chamber	• Dimensions and/or volume	2.3.1	N/A	4.1.2.3
	• Temperature environment for experiment	2.4.1		4.1.2.1
	• Pressure environment for experiment	2.4.2		4.1.2.2 / 4.8
	• Ports, windows, and openings	2.3.5		4.1.2.6
	• Cleaning and access to interior	2.3.2		4.1.2.7 / 4.1.2.8
	• Levitation/positioning	2.3.4 / 2.5.10		4.4
	• Cooling considerations	NRS[1]		4.1.2.1 / App. B
	• Cryocooler capabilities	NRS		App. C
Sample Generation and Handling	• Sample generation	2.5	N/A	4.2
	◆ *Solid particle cloud*	2.5.3		4.2.3
	◆ *Liquid aerosol*	2.5.4		4.2.4
	◆ *Single solid particle*	2.5.5		4.2.5
	◆ *Single liquid droplet*	2.5.5		4.2.5
	◆ *Soot from combustion*	2.5.6		4.2.6
	◆ *In situ generated samples*	2.5.7		4.2.7
	◆ *Low-temperature condensates*	2.5.8		4.2.8
	◆ *High-temperature condensates*	2.5.9		4.2.9
	• Sample manipulation	2.5.10	N/A	4.4
	• Sample storage, pre- and post-experiment	2.5.1 - 2.5.2	N/A	4.6
	• Sample removal post-experiment	2.5.2	N/A	4.6.1 / 4.7.1
Diagnostics	• Optical in-line diagnostics	2.6.1	N/A	4.3.4
	• Imaging	2.6.2	N/A	4.3.5/4.10.3
	• Off-line diagnostics	2.6.3	N/A	4.3.6
	• Experiment-specific diagnostics	2.6.4	N/A	4.3.7
	• Environmental monitoring	2.4 / 2.6.7	N/A	4.3.2
	• g-level and vibrations	2.6.5	3.1.1	4.1.2.4 / 4.3.3
Gas storage and handling	• Gas storage and mixing • Moisture control	2.4.3	3.3.4	4.1.2.5/ 4.5
Waste management	• Remove particles and toxic/corrosive gases from effluents • Waste storage and discharge to space	NRS	3.3.3	4.7
Storage	• Sample pre-experiment • Post-experiment sample • Preserve sample for return to earth for further analysis • Interchangeable hardware	2.5.1 / 2.5.2		4.6
Electrical	• Utilize SSF power	NRS	3.3.5	4.9

Table 5. Cross-Reference and Functional Requirements by Major Subsystems **(Continued)**

Subsystem	Function	S&T Req. Section	SSF/ISPR Accom-modations	Functional Requirements, & Related Analyses
Command and Data Handling	• Provide experiment control • Data acquisition • Station interface • Automation	NRS	3.4	4.1
Structure and General Design	• Compatible with Station module accommodation, ISPR, & LSE • Cabin environment (avionics air, cooling water, fire suppression, LSE)	NRS	3.2 / 3.5 3.1.2 / 3.3.1, 3.3.6 / 3.5	4.11
Other	• Experiment duration and repeats • General experiment operations • High vacuum considerations • Housekeeping considerations	2.7.2 2.7 NRS NRS	3.6	4.2.2.4/App. E 5.2 4.8/App. D 4.12

[1] NRS: no requirement specified

2 SCIENCE AND TECHNICAL REQUIREMENTS

This section presents a listing of the science and technical requirements by categories of experiment parameters (e.g., pressure, temperature, dimensions, diagnostics needs, etc.). It is a cross-reference compilation of the experiment requirements and identifies "holes" or missing information in those cases which were not specified in the original workshop questionnaire. The data are shown in a tabular or graphical form, as appropriate, and summarized in a form useful for development of the facility functional requirements. Analyses of the requirements, trade-offs, and facility functional requirements are discussed in Section 4.

2.1 Database

The database consists of material obtained from two sources: the workshop questionnaire and telephone interviews with the initial experimenters. The updated data obtained during these interviews were included in the database which was issued in its final format on November 1991. The database is included in Appendix A of this report. It is important to note, however, that the database is a supplement to the 1987 workshop questionnaire, and does not replace it. In case of conflicting entries, the database prevails since it is an update to the workshop. The experiment requirements, which are discussed in the remainder of this section, are **derived** first from this database and than from the workshop inputs.

In a number of cases requirements were undefined in the workshop inputs and no additional requirements were available during the update. In other cases the requirements lacked specificity to be useful (a) because the experimenters required additional studies to better define their experiment needs or (b) only qualitative information was provided (e.g., pressure range from 0 to 1 bar -- here 0 must be quantified as 10^{-6}, 10^{-10} bar, etc.): such cases are identified. However, because of the interdependency between various facility subsystems, such cases cannot be left totally unspecified at this time. **Assumed** requirements were prepared on the basis of our best judgment and understanding of the experimenter's science needs, and the overall impact on the system complexity, functionality, and cost. These **assumed** requirements should be reassessed in the future with the Science Working Group (SWG), an essential element for the success of the GGSF program.

2.2 Experiment Categorization

The purpose of categorizing the experiments is to identify commonality between different experiments so that similar functions can be defined. Approaches to categorizing the experiments are not necessarily exclusive. For instance, categories can be developed by:

- Experiment sample type
- Phenomena or physical process
- Range of environmental parameters
- Science discipline
- Inter- or intraparticle forces, and more.

The rationale for choosing these categories is defined. The first approach, **experiment sample type,** defines the method of sample formation, the corresponding diagnostics, the sample positioning, the number and size of particles, etc. Examples of categories that were identified include:

- Liquid aerosols. A cloud of droplets, generated from a liquid sample, which fills the test chamber volume.
- Solid particle cloud. A cloud of solid particles, dispersed from a dry powder, which fills the test chamber.
- Soot. A cloud of soot which is generated from hydrocarbon fuels, typically by combustion or pyrolysis.
- High-temperature condensates. A cloud of particulate matter formed by condensation of vapors; these could include high-temperature metals and silicate.
- Low-temperature condensates. A cloud of particulate matter formed by condensation of vapors; these could include ices from water, ammonia, methane, and carbon dioxide.
- Single liquid droplet. A single droplet prepared and admitted into the chamber.
- Single (or a few) particles. Particles that must be positioned and controlled inside the chamber.
- *In situ* generated samples. Aerosol particles that are generated by irradiation of precursor gas with UV, RF, or radiation by other portions of the electro-magnetic spectrum.

These techniques are nonexclusive; for instance, the dispersion of solid condensation nuclei into the chamber may be necessary in order to condense vapors (although supercooling the vapor would also lead to a homogeneous nucleation). Hence, more than one type of sample generation may be required for one particular experiment.

The grouping of the proposed experiments by the experiment sample type is shown in Table 6. As noted above, some experiments appear in more than one category. Later on we will show that the method of sample preparation is not only a function of the above categories. In fact, the test chamber pressure, temperature, the specific size distribution of the particulate matter, and other parameters as well, dictate the specific generation technique. This subject is discussed in detail in section 2.5

Table 6. Experiment Categorization by Sample Type
(Numerals refer to experiment number in Table 1)

Solid Particle Cloud	Liquid Aerosols	Soot and Smokes	High-Temp. Condensates	Low-Temp. Condensates	Single Droplet	Single (few) Particles	*In Situ* Formation
1, 3, 5, 8, 13, 15, 17, 18	11, 18, 19, 20	3, 6, 13, 17, 21	10, 16	1, 2, 3, 4, 6, 7, 8, 10, 15, 16	12	1, 2, 4	9, 13, 14

The second approach to experiment categorization is by the **phenomena or physical process** under investigation, for instance:

- Collision experiments between two particles
- Agglomeration and coagulation experiments
- Condensation, nucleation, evaporation experiments.

This classification approach basically shows the specific functions that must be performed during the experiment. For instance, temperature control is required for the condensation evaporation experiments, or particle positioning and acceleration is required for the

collision experiments. These categories may also correlate to the overall experiment duration. Collision experiments are short in duration, while aggregation experiments may require an extended period of observation. As discussed before, one experiment may belong to more than one category. Table 7 shows the experiments' classification.

Table 7. Experiment Categorization by Physical Process

(Numerals refer to experiment number in Table 1)

Collision	Aggregation/ Growth	Condensation	Optical Properties	Crystal Growth	Bacteria Growth
1, 2, 4	1, 5, 8, 10, 11, 13, 14, 15, 18, 21	3, 6	7, 9, 15, 17	12	19, 20

The third approach is by the range of **environmental parameters**, i.e., the pressure and temperature of the specific experiment conditions. For instance, some experiments must be performed at elevated temperatures up to 1,200 K, while others require temperatures down to 10 K. Some experiments require elevated pressure of several bars, while others require pressure levels in the range below a microbar. These types of requirements impose specific functional requirements on the facility and identify experiments that may be performed in a similar enclosure. The classification of the experiments according to the pressure and temperature range is shown later. (see Section 2.4 Tables 12 and 14 and Figures 6 and 7).

The fourth approach is by the **science discipline**. This categorization method is discussed in the workshop proceedings, and is included in Table 8 for completeness; it does not contribute to the identification of commonality in facility functions.

Table 8. Experiment Categorization by Science Discipline

(Numerals refer to experiment number in Table 1)

Exobiology and Life Science	Planetary Science	Astrophysics	Atmospheric Science	Physics and Chemistry
9, 11, 12, 14, 17, 19, 20	1, 4, 5, 14	13, 15, 16, 17	2, 3, 6, 7, 8, 14, 18	2, 9, 10, 18

The fifth approach is by the type of **inter- or intraparticle forces** that are investigated. Because of the small magnitude of these forces, disturbances due to acoustic, turbulence, vibrations, electrical charges, etc., may be detrimental to the experiment, imposing additional requirements on various facility functions. The experiments are divided accordingly in Table 9.

Table 9. Experiment Categorization by Forces Under Investigation

Type	Exp. No.
van der Waals, electrostatic, and chemical surface bonding experiments	1, 2, 5, 8, 16, 18
Dipole/dipole interaction or dipole/electrostatic	13
Not specifically investigating forces	3, 4, 6, 7, 9, 10, 11, 12, 14, 15, 17, 19, 20, 21

As mentioned earlier, these categories are not exclusive and also most experiments do not group together in categories from categorization to categorization. Nevertheless, these categories (and possible others as well) form a convenient method for generating classes of functional

requirements. These categories are used to formulate "composite" experiment requirements and to define the envelope of the required facility functional performance.

Figure 3 shows, for each experiment, the materials type used for sample generation, the range of pressure and temperature in the experiment, the physical processes acting on the sample during the experiment, the size range of the sample particles involved, and the key observation or measurement to be performed. This summary serves as an introduction, more detailed and quantitative requirements for these and other categories are discussed and documented in the following sections. A schematic representation of the sample (particle) size range for the various experiments is shown in Figure 4.

2.3 Chamber

2.3.1 Volume and Dimensions

Chamber dimensions and volume requirements for the experiments are summarized in Table 10 and Figure 5, respectively. Shown in the figure are the experimenters' requirements; in some cases the minimum or maximum dimensions were specified, in others, the volume. A calculated volume, listed in the last column of Table 10, is based on the given dimensions and is provided to allow a comparison of all chamber requirements on a common basis. Figure 5 contains reference to various chamber sizes; the details of chamber size selection is found in section 4.1

Table 10. Chamber Size Requirements

Exp. No.	Minimum Dimension or Minimum Diameter cm	Maximum Dimension or Maximum Diameter cm	Minimum Volume cm^3	Calculated Volume, cm^3
1	10	meters	NS	>523
2	NS	NS	1	~ 1
3	NS	NS	1E+05	>1E+05
4	20	NS	NS	>4,189
5	20	NS	NS	>4,189
6*	20 x 1 x 30	30 x 2 x 50	NS	600 - 3,000
7	6 (dia.) x 4	NS	120	>113
8	3 x 30 (dia.)	10 x 50 (dia.)	NS	2,120 - 19,635
9	15 (dia.) x 25	NS	NS	> 4,417
10	NS	NS	NS	-
11	50	NS	NS	> 65,449
12	NS	NS	10	>10
13	10	50	NS	524 - 65,499
14	10	NS	NS	>524
15	25	NS	NS	>8181
16	10	1 m^3 max. vol.	NS	$523 < V < 10^9$
17	20	NS	NS	>4,189

Table 10. Chamber Size Requirements (Continued)

Exp. no.	Minimum Dimension or Minimum Diameter cm	Maximum Dimension or Maximum Diameter cm	Minimum Volume cm^3	Calculated Volume, cm^3
18	5 x 5 x 5	15 x 15 x 15	NS	125 < V < 3,375
19	NS	NS	1E+06	~10^6
20	NS	NS	1E+06	~10^6
21	10 (dia) X 100	NS	NS	>7,853

NS: not specified.
* - Continuous Flow Diffusion (special) Chamber.

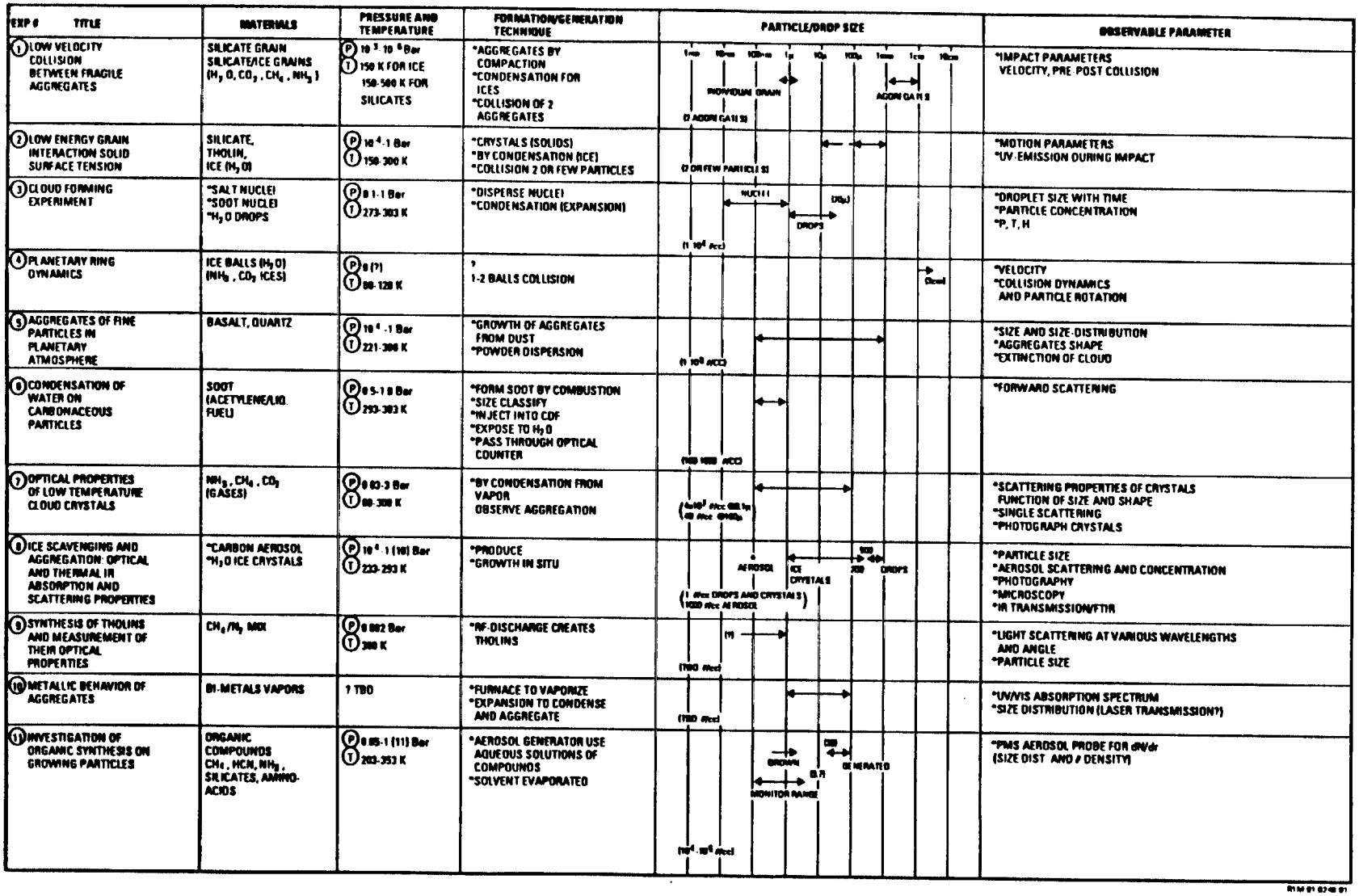


Figure 3. GGSF Overall Experiments Overview

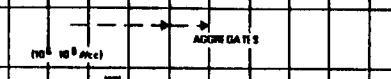
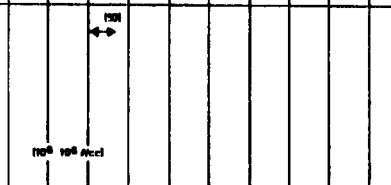
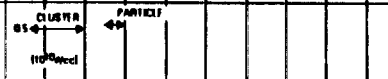
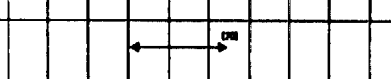
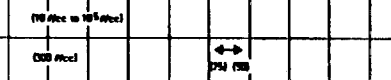
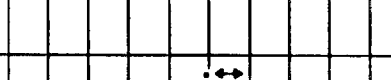
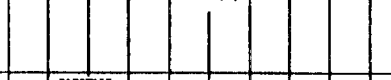
EXP # TITLE	MATERIALS	PRESSURE AND TEMPERATURE	FORMATION/GENERATION TECHNIQUE	PARTICLE/DROP SIZE	OBSERVABLE PARAMETER
(12) CRYSTALLIZATION OF PROTEIN CRYSTAL GROWTH INHIBITORS	PROTEIN/H_2O SOLUTION	(P) 1 Bar (T) 277-293 K	*SUSPEND 1 DROP *ALLOW TO DRY-EVAPORATE H_2O		*COLLECT CRYSTAL
(13) DIPOLAR GRAIN COAGULATION AND ORIENTATION	MgO SMOKE, OLIVINE, PYROXENE	(P) 0-1 Bar (T) 77-300 K	*MgO BY BURNING Mg WIRE *OTHER BROUGHT FROM EARTH		*SIZE GROWTH IN E-FIELD
(14) TITAN ATMOSPHERE AEROSOL SIMULATION	ORGANICS CH_4 /N_2 /H_2 THOLINS	(P) .001-1 Bar (T) 200-300 K	*UV-IRRADIATION PHOTOLYSIS *E DISCHARGE		*SCATTERING
(15) SURFACE CONDENSATION AND ANNEALING OF CHONDRITIC DUST	(1) REFRACTORY OXIDES Al_2O_3, TiO_2, MgO (*CRYSTALLINE, OR *AMORPHEOUS) (2) METAL BEARING GASES C_nO, F_eO, M_nO, OR METAL-CARBIDE, METAL-HYDROGEN	(P) 10^{-6}-10^{-3} Bar (T) 500-1200 K	*DISPERSE SOLID GRAINS *INTRODUCE GASES AND COOL SLOWLY		*CLOUD OPTICAL PROPERTIES
(16) STUDIES OF FRACTAL PARTICLES	*METALS *SILICATES *ICE COATED METALS AND SILICATES	(P) 1 Bar (T) 4-300 K	*EVAPORATE METALS/SILICATES IN CRUCIBLE *CONDENSE IN COOL CHAMBER		*OPTICAL PROPERTIES
(17) OPTICAL PROPERTIES OF PARTICLES AND CLUSTERS	*CLUSTERS OF PAH *CARBON GRAIN *MINERALS *ICES (H_2O/CO/NH_3)	(P) 10^{-7}-10^{-6} (T) 10-300 K	*HEATING OF SOLIDS *INTRODUCE INTO CHAMBER BY A JET *SUSPEND A SINGLE CLUSTER		*OPTICAL PROPERTIES
(18) EFFECT OF CONVECTION ON PARTICLE DEPOSITION AND COAGULATION	*LIQUIDS AND SOLID MICROSPHERES OF VARIOUS MATERIALS	(P) 1 Bar (T) 293-373 K	*LIQUIDS - VOAG *SOLIDS - DISPENSER		*SIZE DISTRIBUTION
(19) GROWTH AND REPRODUCTION OF MICRO-ORGANISMS IN A NUTRIENT AEROSOL	SOLUTION OF MICROBES IN NUTRIENT SOLUTION	(P) 1 Bar (T) 283-313 K	NEBULIZER		*# DENSITY AND SIZE
(20) LONG TERM SURVIVAL OF HUMAN MICROBIA IN AND ON AEROSOLS	SOLUTION OF MICROBES IN NUTRIENT SOLUTION	(P) 1 Bar (T) 283-303 K	ATOMIZER/NEBULIZER		*NUMBER DENSITY AND SIZE
(21) STUDY OF SMOKE AGGLOMERATES	CARBON SMOKE	(P) 1 Bar (T) 298 K	COMBUSTION		*SIZE AND NUMBER

Figure 3. GGSF Overall Experiments Overview (Cont.)

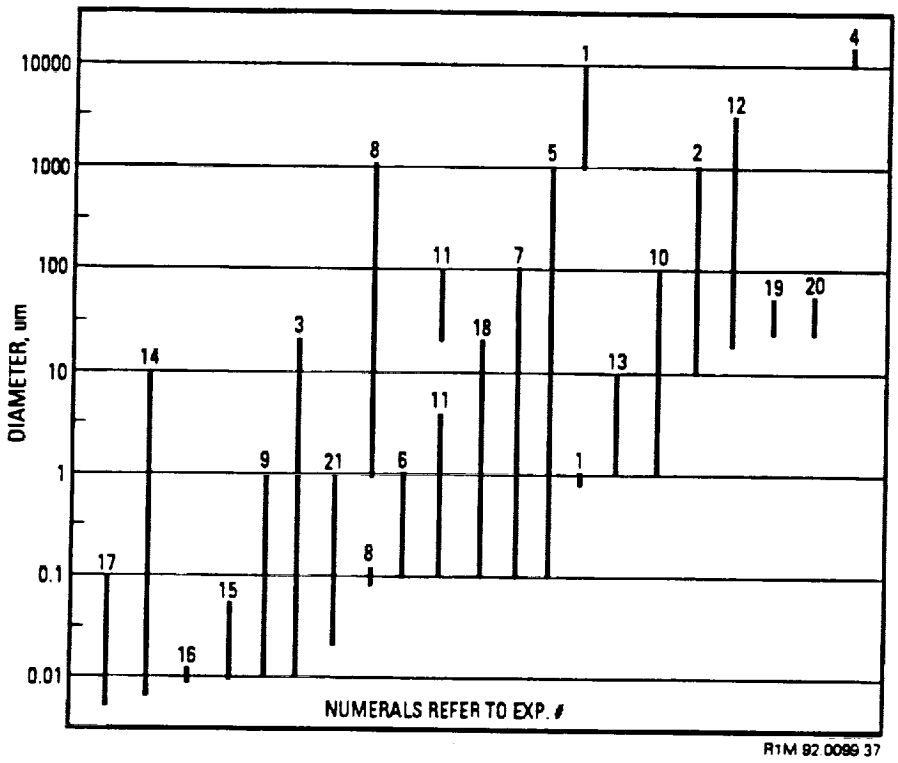


Figure 4. GGSF Experiments Grain Size Distribution Arranged by Size

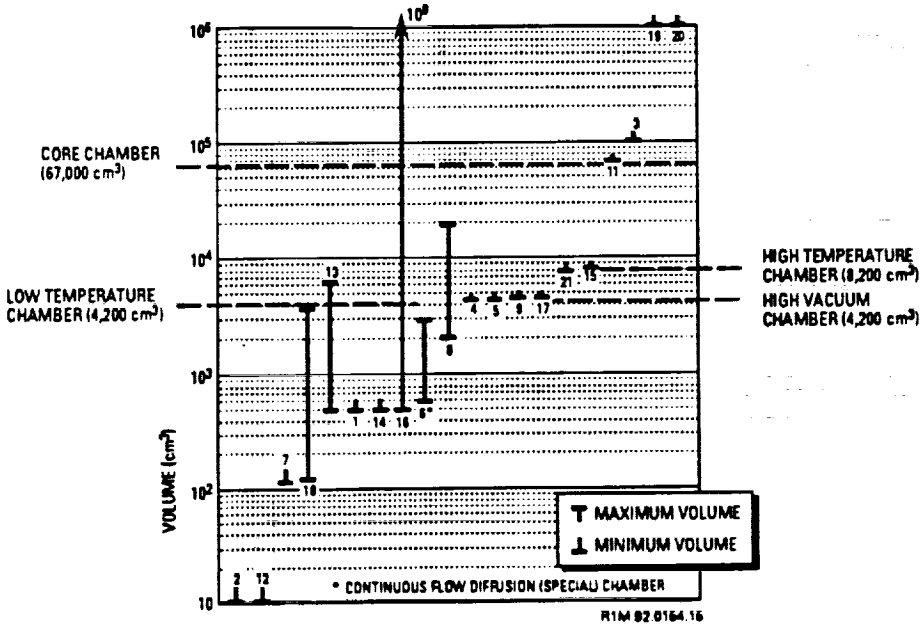


Figure 5. Volume Requirements for Experiments by Increasing Minimum Size

In the selection of chamber size for the facility, other factors and requirements must be considered, such as:

- Diffusion, settling and residence time considerations
- Rack size (there is a physical limit to the chamber size that can be accommodated in the rack)
- Chamber cooling requirement (the cooling capacity is limited and final attainable temperature is ultimately dependent on the mass that must be cooled, and by the thermal load on the chamber; these in turn depend on chamber size, number of windows, and ports)
- Size and heat rejection power of the available cryocooler (limited by electrical power and rack space)
- Volume of consumables (gases and sample materials) used for each chamber fill and the impact on the logistics of resupplying the GGSF.
- Pressure vacuum requirements may require special specific chamber to be considered.

TECHNICAL ISSUES

- *A number of experiments may require an experiment-specific chamber either due to geometry, pressure, temperature ranges, or volume.*
- *With the exception of the 10^6 cc requirements, a 65,500 cc chamber is the largest needed.*
- *Most experiments fit into a 4,200 cc chamber.*

2.3.2 Chamber Cleaning Requirements

The experiment requirements regarding the cleanliness of the test chamber range from "not critical," "filtered air or dust-free," "cleaned observation windows," to "sterilized." Since all the experiments deal with mixtures of gases, organic gases, particles, etc., contamination between repeats of the same experiment and cross-contamination between different experiments is of concern. Similarly, buildup of dust or other deposits over observation or diagnostic windows may block the view or give false readings in some instruments. The requirement is, therefore, to allow some capability of chamber cleaning in order to avoid or minimize the impact of such occurrence.

TECHNICAL ISSUE

- *Quantitative cleanliness requirements for the chamber and the windows should be defined or derived on the basis of the purity of sample requirements and based on optical access requirements. One possible approach for specifying cleanliness may be based on clean-room categories.*

2.3.3 Diagnostics

The experiment chamber must provide access to various types of in-line, off-line, and in-chamber diagnostics for the characterization of the particulates and the specific event under investigation. In-line diagnostics are typically optical techniques that utilize spectral and spatial extinction properties of the particles for their characterization (e.g., scattering, transmission, etc.) Off-line technique extract samples into various instruments which utilize either optical properties or chemical physical properties for the sample characterization (e.g., electrical mobility analyzer, condensation nuclei counter, etc.) In-chamber techniques are experiment-specific instruments

that have to be placed inside the experiment chamber to perform the required characterization (e.g., measure particle charge, strength of fractal particles, and particle dipole moment, etc.) This subject is covered in two separate entries: access ports in section 2.3.5 and diagnostics in Section 2.6.

2.3.4 Levitation and Positioning

The chamber functions and design are significantly affected by the levitation and positioning requirements. Because of the extensive nature of this subject, it is discussed separately under sample manipulation in section 2.5.10.

2.3.5 Access Ports

The workshop questionnaire revealed that a large number of ports of various types will be needed. These requirements are summarized in Table 11. There may also be **derived** requirements for additional ports such as cleaning and access ports. The functional requirements or trade off analyses related to the ports are discussed in Section 4.1.2.6.

Table 11. Access Port Requirements

Exp. No.	Viewing	Lighting	Instrument	Entry	Sampling	Total
1	2 - 3	1 - 2				3 - 5
2	1		1			2
3	2					2
4	3 orthogonal					3
5	3	2	3	1	1[1]	10
6				2	1	3
7	3[2]					3
8	> 5 total					> 5
9						
10						
11				3 - 4	1	4 - 5
12	1			1	1	3
13	2	2		3	1	8
14		2		1	1	4
15	4			5 - 7	1	10 - 12
16	3	2	4	1		10
17	2 - 6		2	2		6 - 10
18			2	2		4
19				1		1
20				1		1
21	2					2

[1] Can be multipurpose port

[2] 180° viewing angle plus top/bottom photography ports

2.4 Experiment Environment

2.4.1 Temperature Environment for Experiments

The temperature range requirements for the experiments are shown in Figure 6, and the experiments are grouped according to the minimum and maximum required temperature in Table 12. Figure 6 contains reference to various chamber sizes which are discussed in section 4.1.2.3. The temperature ranges shown in the table were selected on a basis of level of difficulty in achieving that range of operating temperature. This is not a "hard" range, and it is based on a preliminary thermal analysis discussed in Appendix B. As a whole the minimum temperature required is 10 K (desires were expressed for 4 K), and the maximum is 1200 K. One experiment (4) requires operations only in the cryogenic temperature range. Another experiment (15) requires operations at only elevated temperatures. Most experiments can perform some of their operations in the range between 200 and 360 K. Most experiments that do require lower temperatures may be satisfied in the range between 60 and 200 K. Temperature control, shown in Table 13, is required by most experiments and varies from ±0.001 to ±50 K. Control to ±1 K at room temperature satisfies most of the experiments.

Technical Issues

- *Experiments 16 and 17 require cooling to extremely low temperatures (4 and 10 K, respectively).*
- *Experiment 15 requires very elevated temperatures (500 to 1200 K).*
- *Feasibility of temperature control to ±0.001K.*

Table 12. Experiment Temperature Requirements

Lower Operating Limit (K)	Experiment no.	Upper Operating Limit (K)	Experiment no.
10 to 150	1, 2, 4, 7, 13, 16, 17	120	4
200 to 270	5, 8, 11, 14, 19	293 to 303	2, 3, 6, 7, 8, 9, 12, 13, 14, 16, 17, 20, 21
273 to 300	3, 6, 9, 12, 18, 20, 21	313 to 373	5, 11, 18, 19
500	15	500	1
		1,200	15

2.4.2 Pressure Environment for Experiment

The pressure range required by the experiments varies from 10^{-10} to 3 bar (experiments 8 and 11 initially expressed desire for 10 and 11 bars), as shown in Figure 7. Figure 7 contains reference to various chamber sizes which are discussed in section 4.1.2.3. One experiment (17) requires high and ultrahigh vacuum. Another experiment (7) requires an upper limit of 3 bars, but has a broad range of operations from 0.03 bar. The experiments are grouped according to their minimum and maximum pressure range, within somewhat arbitrary groupings in Table 14. It can be seen that most experiments can be satisfied with a minimum pressure no lower than 10^{-6} bar and no higher than 1 bar. About 30% of the experiments operate exclusively at 1 bar.

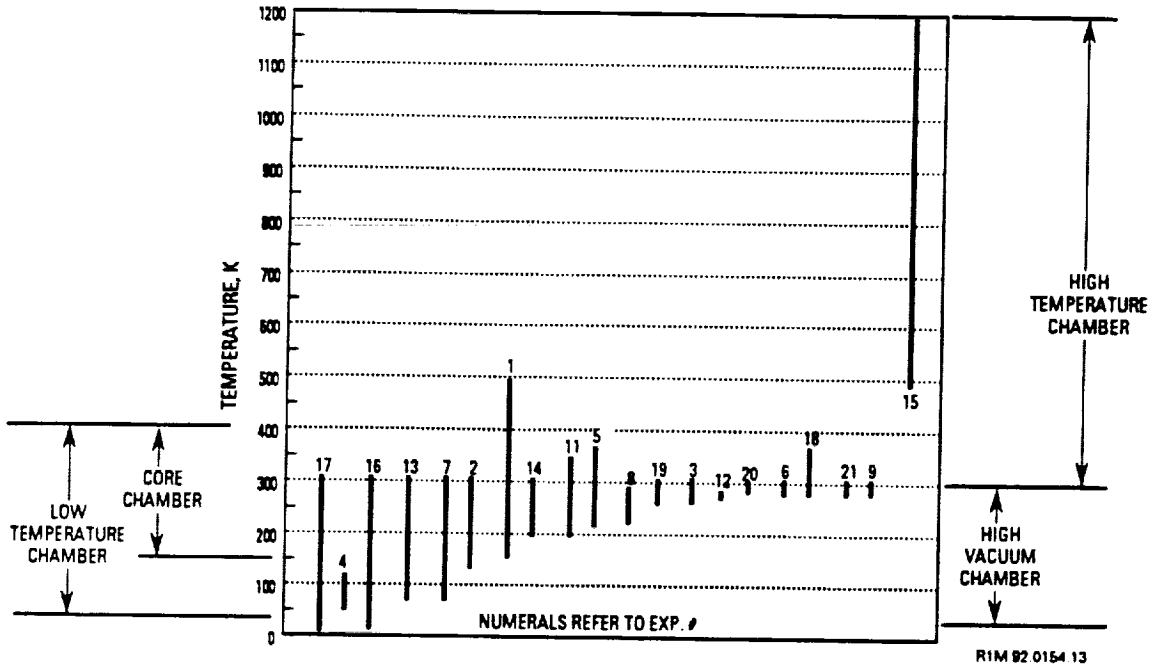


Figure 6. Temperature Range Requirements Arranged by Increasing Lower Temperature Limit

Table 13. Pressure Measurement Accuracy and Temperature Control Requirements

Exp. No.	Pressure Measure Accuracy	Temperature Control, ±°C	Exp. No.	Pressure Measure Accuracy	Temperature Control, ±°C
1	Control X10 Measure X2	10	12	5%	1 to 2
2	NC	NC	13	5 mbar	10
3	0.01mbar	0.001	14	10%	10
4	NS	2	15	<10%	25, (but 1 @ center)
5	0.1 mbar	NS	16	10%	50 @ 1,000 K 10 @ 20 K
6	NC	0.1*	17	X2	< 10
7	<10%	0.1	18	10%	< 5
8	1%	0.1*	19	NS	2
9	± ½ mbar	NS	20	NS	2
10	NS	NS	21	2%	1
11	5 mbar @ 50 mbar 0.4 bar @ 11 bar	5	NS: Not specified. Xn: A factor of n. NC: Not critical		

* - Temperature gradient required.

Pressure monitoring is required for most, but not all of the experiments as shown in Table 13. Monitoring accuracy of ±1% is generally acceptable. In discussions with the experimenters a clarification was made that no pressure control is required during an experiment run with the exception for experiments requiring experiment-unique expansion chamber.

Table 14. Experiment Pressure Requirements

Lower Operating Limit (bar)	Experiment No.	Upper Operating Limit (bar)	Experiment No.
1.0E-10	17	1E-08	17
1.0E-06 to 1.0E-02	1, 2, 4, 5, 8, 9, 13, 14, 15	1E-03 to 1E-01	1, 9, 15
1.0E-02 to 0.5E00	3, 6, 7, 11	1	2, 3, 4, 5, 6, 8, 11, 12, 13, 14, 16, 18, 19, 20, 21
1	12, 16, 18, 19, 20, 21	3	7
		10 - 11*	8, 11

* Desired range.

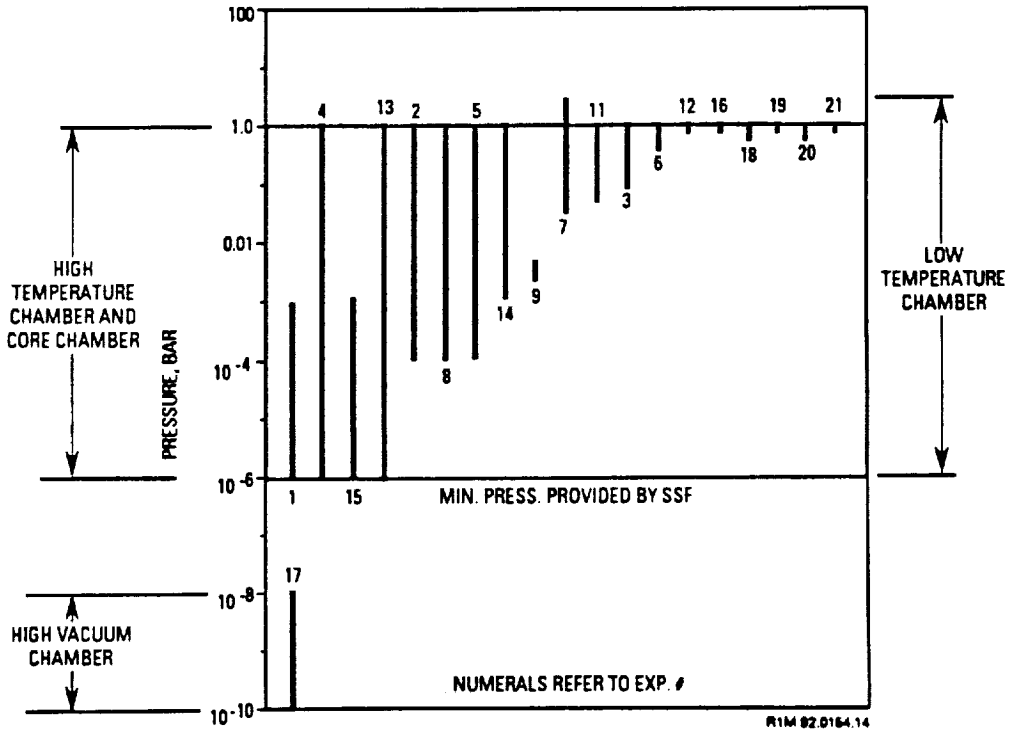


Figure 7. Pressure Range Requirements by Increasing Lower Operating Limit

For those experiments that undergo a large temperature change, the pressure will change significantly as well because the pressure will not be actively controlled. Since the cooling process is neither isentropic nor adiabatic, the pressure changes are in direct proportion to the temperature change. So, for a temperature change from 300 K to say, 80 K, the pressure will change by a factor of 300/80=3.75. The experimenters should indicate which pressure is

specified: the initial pressure in the chamber or the pressure during the observations, i.e., after the cool-down, or whether active pressure control is required.

TECHNICAL ISSUES

- *GGSF is to provide temperature sensor(s) for the measurements of chamber wall and gas temperature.*
- *GGSF is to provide pressure measurement sensor(s) for the full range from high vacuum to above atmospheric.*
- *Operating temperature below, or near, the triple point of gases in the chamber is incompatible with having those gases in the chamber.*
- *In general, cryo-temperature is compatible with low pressure; the pressure and temperature range for some experiments specify conditions that may be inconsistent.*
- *The requirement for pressure (and temperature) monitoring versus controlling should be clearly specified.*
- *It is not clear whether the chamber wall or gas temperature are specified; also local wall temperature gradients must be considered as inevitable to some extent.*

2.4.3 Gas Composition and Humidity

The experiments require gases or mixtures of gases in the chamber. The gases are generally common to several of the experiments, although some experiments require unique specialty materials. Several experiments require a mixture of gases that may vary from one run to the next. A summary of the gases required by the different experiments, and the accuracy in the initial composition control, is shown in Table 15.

There is no specific mention in the workshop questionnaire of analytical systems to measure the composition of the gas mixtures. The use of a gas chromatograph (GC) as a diagnostics apparatus was mentioned by experiments 11 and 16. Discussions with the experimenters indicated that there is a need to measure the mixture composition during and after the experiment. Therefore, some analytical system is required. This requirement should be carefully assessed since there are some difficult gas mixture components to analyze as shown in Table 15 under the column "other."

Several experiments require a variable level of humidity, which ranges from a dry environment up to 100% relative humidity (RH). However, the RH is only meaningful when associated with a temperature. The S&T requirements should clearly associate the RH with a temperature. A summary of the relative humidity levels, and the required control, is shown in Table 16. These requirements have been interpreted as follows: *The RH specifications apply to the mixture being introduced into the chamber, as opposed to control of the RH in the chamber during the experiment.* The latter interpretation may be applicable, though, to experiments 19 and 20, which require 100% RH. An unambiguous specification of the RH requirements is needed for each experiment.

Table 15. Consumables Required by Experiment

(not including sample materials, e.g., aerosol, solids, etc.)

Exp. No.	Air	N_2	H_2	O_2	H_2O	D_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				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	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.

Table 16. Relative Humidity Requirements by Experiment

Exp. No.	RH Range %	Control ±%	Exp. No.	RH Range %	Control ±%	Exp. No.	RH Range %	Control ±%
1	NS	NS	8	NS	0.5	15	0	Dry
2	0 - 50	NS	9	0	NA	16	0	NA
3	NS	0.01	10	NS	NS	17	0	Dry
4	NS	NA	11	0 - 100	5	18	0 - 100	NC
5	NS	2	12	50	1	19	100	NA
6	NS	5	13	NS	NS	20	100	NA
7	0	<10	14	0	Dry	21	to 70	NA

NA. Not applicable. NC: Not critical. NS: Not specified.

TECHNICAL ISSUES

- *There may be some technical difficulty associated with analysis of some gases; the required measurements, accuracies, or analytical system should be specified in more detail.*
- *The relative humidity requirement should be specified with an associated temperature. The requirement should also clarify whether or not it must be applied inside the chamber.*

2.5 Sample Generation and Handling

The workshop questionnaire provided information regarding particle size and concentration, see Figure 8. The experimenters should clarify whether the specified sample size-range was for the initial sample or whether it included the size of the sample after undergoing some physical chemical processes during the experiment. Also, requirement should be stated as to the size uniformity within the initial sample.

The sample generation requirements were divided into the type of generators that may be required for the various substances, materials, and phases used as samples. These **derived** sample generation techniques were identified and mentioned in section 2.2, Experiment Categorization, Table 6. Some experiments require multiple techniques (e.g., particle dispersion followed by condensation of vapor produced in another generator).

In the following subsections these **derived** generation techniques are used as the basis for grouping the experiments; for each group the type of particles, their size, and the number density are given in tabular and graphical forms. The tables also specify the pressure and temperature in the experiment chamber into which the particles must be dispersed. As discussed later, these parameters may, in some situations, have a major impact on the appropriate generation/ introduction technique. In several experiments it was noted that the particle residence time may not be compatible with the characteristic sedimentation (in vacuum) or diffusion times. These issues are noted here and analyzed in some detail in section 4.1.2.4. We begin this discussion with sample handling before and after the experiment.

TECHNICAL ISSUES

- *GGSF experiment chamber is to provide access for multiple sample (particle, droplet, etc.) formation and generation hardware creating complex chamber design.*
- *The acceptable sample (particle, droplet, etc.) size distribution requirement should be specified, or explicitly stated e.g., "not critical," in order to develop performance criteria for the sample generation hardware.*

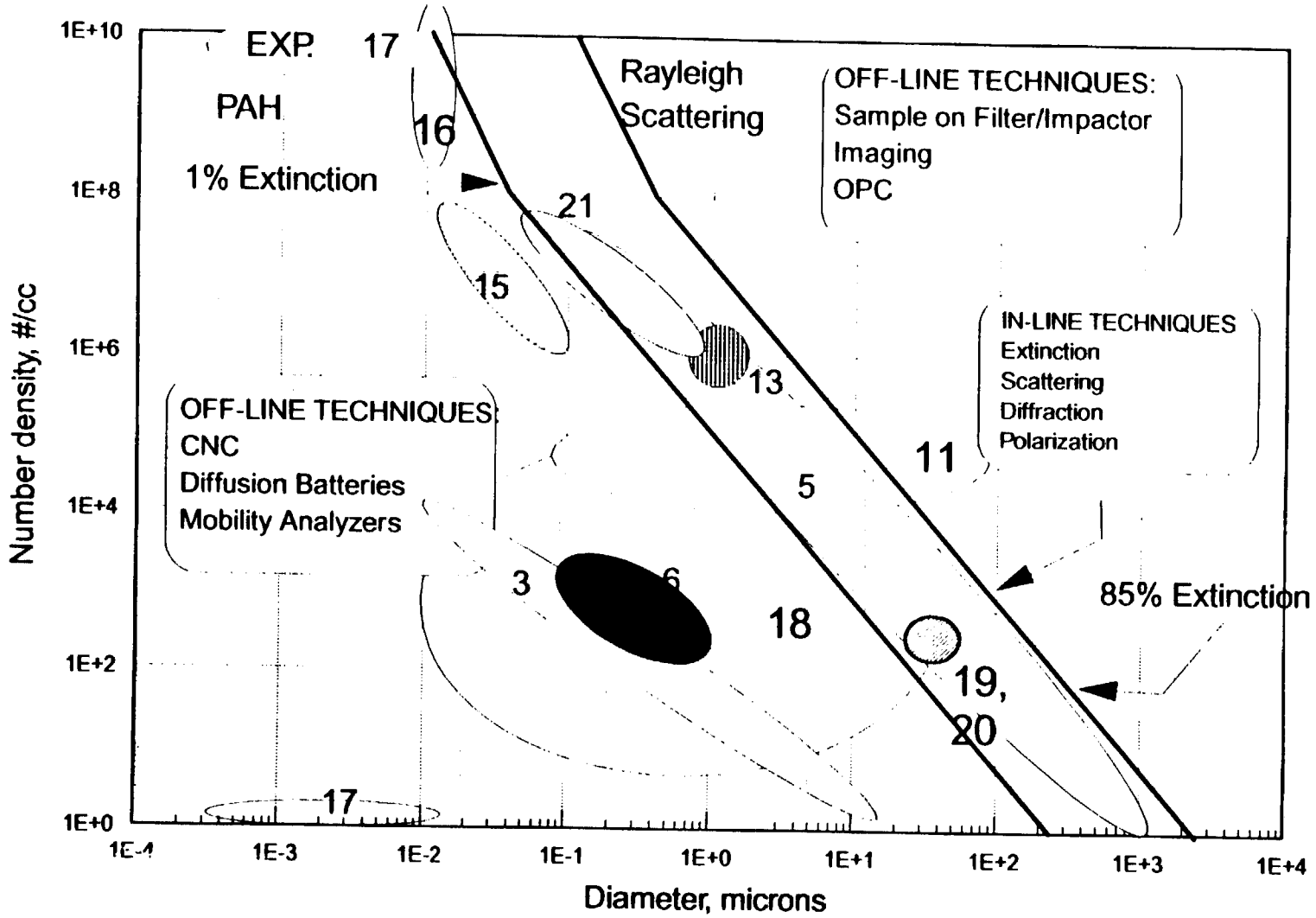


Figure 8. Summary Particle Size and Concentration Requirements by Type

2.5.1 Sample Preparation and Handling

The sample materials to be stored and prepared for the experiments include solid powders, liquids, solids (e.g., metals and silicates to be vaporized), as well as hydrocarbon fuels for soot generation, and biological materials. Gases for the chamber environment are not included here; these are discussed separately in sections 2.4.3 and 4.5. The following **derived** functional requirements have been identified (these were not specifically requested in the questionnaire) for various samples:

- Storage space
- Environmental control (temperature, moisture, vibrations)
- Sample loading into the generator (e.g., powder disperser or liquid atomizer)
- Reloading for repeat experiments
- Removal of sample remains for a subsequent experiment operation.

2.5.2 Post-Experiment Sample Retention and Return

Two thirds of the experiments require retention of samples for further analysis. In the absence of definite information regarding analyses capabilities on board SSF (section 3.5), this may imply a sample return to Earth. The samples are typically end products of the experiment. In some cases special care must be provided for fragile samples (vibration control) or those requiring specific environmental control (e.g., temperature). The experiments which need further sample study are shown in Table 17.

Table 17. Experiments Requiring Sample Return

Sample Return: Exp. No.	5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 19, 20

The **derived** requirements for sample retention include:

- Sample removal from chamber (typically solid particles or liquid droplets)
- Capture of samples
- Retention for return to Earth
- Environmental control (in some cases) for delicate or sensitive samples (temperature, vibration, humidity, etc.).

2.5.3 Solid Particle Cloud

The solid particle dispersion requirements are shown in Table 18. Solid particle clouds are formed from powder of the specific material by dispersing the powder into the experiment chamber. The powder should be presifted to the desired size range and distribution. The disperser should function such that particle agglomeration forces are overcome to avoid clumps of multiple particles. Some experiments require the formation of a cloud in vacuum and the introduction of the particles with a carrier gas may be incompatible with such a requirement, unless a very small amount of carrier gas (relative to the chamber volume) is used. There seems to be no simple way to introduce the particles with a large amount of a carrier gas and then pumping the gas out without removal (and loss) of the particles in the process.

Some experiments require low temperature. When the particles are introduced into the chamber they are likely to be at ambient cabin temperature. The cooling of the particles is primarily by conduction through the gas (free convection is negligible at μ-g) and radiation to the walls (exclusively by radiation for the vacuum experiments). Either process takes time to reach equilibrium at the desired temperature. It is assumed that the particle temperature can be

adequately inferred from the wall temperature measurement and by analysis, and no direct measurement of the particle temperature is required.

Table 18. Science Requirements for Solid Particle Cloud Dispersion

Experiment no.	Materials	Size (μm)	Number Density (No./cc)	Pressure Range (bar)	Temperature Range, (K)
1	Silicate grain	~1	TBD	10^{-3} - 10^{-5}	150 - 500
3	Salt	0.01 - 1	1 - 10^{4}	0.1 - 1.0	273 - 303
5	Quartz, basalt	0.1 - 1,000	1 - 10^{8}	10^{-4} - 1	221 - 366
8	Carbon	0.1	1,000	10^{-4} - 1 (10)	233 - 293
13	Olivine; pyroxene	1	1.0E+05	0 - 1	77 - 300
15	Al_2O_3, TiO_2, MgO	0.01 - 0.05	10^{5} - 10^{8}	10^{-6} - 10^{-3}	500 - 1200
17	Carbon grain (amorphous, hydrated, graphite), silicates	0.05 - 0.1	1.0E+10	10^{-10} - 10^{-9}	10 - 300
18	Microspheres (TBD)	0.01 - 20	10 - 10^{4}	1	293 - 373

For those experiments that require low temperature as well as vacuum, introducing the particles at ambient cabin temperature may be a problem. In a vacuum the particles "fall" due to the sedimentation at the residual g-level in a short time (about a minute for a reasonable chamber size; see Appendix E). And although the particle cooling time may be short relative to the sedimentation time,[4] the chamber cool-down time may be very long relative to the sedimentation time. This implies that for experiments requiring low temperature and low pressure in the chamber, the particles should be introduced into the chamber at the experiment temperature.

2.5.4 Liquid Aerosols

The liquid aerosol requirements are summarized in Table 19. All the experiments in this category operate within the range of atmospheric pressure, with experiment 11 extending the range to the medium vacuum region. The vapor pressure of the liquid sample should always be lower than the specified chamber pressure. The freezing point of the solution for experiment 11 is not known, but it is **assumed** that the aerosol is formed at room temperature and then is cooled to the desired temperature inside the chamber. It seems that for performing the low-temperature, low-pressure conditions in experiment 11, the aerosol may have to be introduced after the chamber has been cooled down (see discussion in section 2.5.3).

[4] The thermal diffusivity, $D=k/Cp\text{-}d$, (where k is the thermal conductivity, Cp is the specific heat, and d is the density) of quartz is roughly 3.4×10^{-7} m^2/sec. The characteristic cooling time is on the order of R^2/D where R is the particle radius. So for a 100-μm particle the characteristic cooling time is of the order of 30 msec.

Table 19. Science Requirements for Liquid Aerosol Generation

Experiment No.	Materials	Size (μm)	Number Density (No./cc)	Pressure Range (bar)	Temperature Range, (K)
11	Liquid solution of organic compounds: formaldehyde, HCN, NH_3, CH_4, H_2O, amino-acids	0.1 - 0.2	10^4 - 10^5	0.05 - 1 (11)	203 - 353
18	TBD	0.01 - 20	10 - 10^5	1	293 - 373
19	Nutrient, microbe solution	25 - 50	300	1	263 - 313
20	Nutrient, microbe solution	25 - 50	300	1	283 - 303

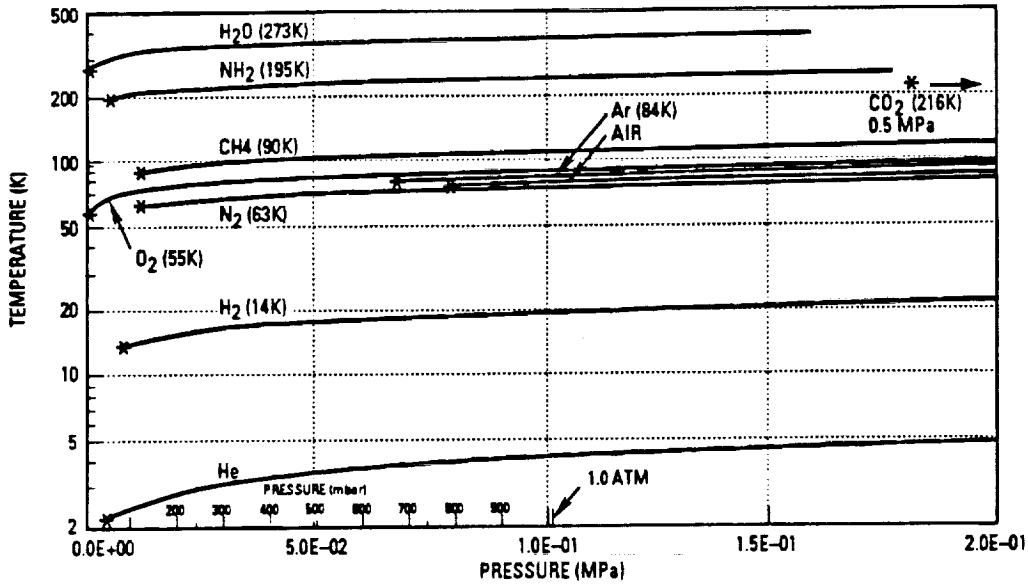
2.5.5 Single Drop or Single Particle

These experiments include requirements for a single or a few individual particles/droplets. A summary of the requirements in this category is shown in Table 20. All the experiments under this category require specific techniques to form and position the droplet or particle, and to manipulate it, if desired. Further, even within one experiment, particles that are submicron and those which are millimeter in size require different types of handling (if for no other reason than the submicron size cannot be seen whereas the millimeter particle is clearly seen by the eye). The issue of effecting collisions between small particles requires further attention, and the subject is treated in section 4.4.4.

Table 20. Science Requirements for Single Drop/Particle Generation

Exp. No.	Materials	Size	Number	Pressure Range, (bar)	Temperature range, (K)
1	Silicates and ice coated silicates	1 - 10 mm	2	10^{-3} - 10^{-6}	150 - 500
2	Silicate, tholin, Ice (H_2O)	10 μm - 1 mm	2 or a few	10^{-4} - 1	150 - 300
4	H_2O, NH_3, CO_2	1 - 3 cm	1 or 2	TBD	60 - 120
12	Protein H_2O solution	20 - 3,000 μm	1	1	277 - 293

Special attention should be given to the formation of CO_2 ices. Figure 9 shows the vapor pressure and the triple point for various substances. Whereas all other gases have the triple point below atmospheric pressure and temperature, carbon dioxide is unique in having the triple point at about 5 bars. Ices of all the other gases can be formed by controlling the chamber pressure and temperature, but CO_2 ice cannot be formed that easily within the range of specified pressure and temperatures. CO_2 ice can be formed by rapid cooling, such as when it is expanded from a high-pressure bottle but a special technique, appropriate for GGSF, must be developed and tested.



TRIPLE-POINT DATA					
SUBSTANCE	T (K)	P (mbar)	SUBSTANCE	T (K)	P (mbar)
HELIUM 4	2.172	50.40	AMMONIA	195.40	60.75
HYDROGEN	13.84	70.4	SULFUR DIOXIDE	197.68	1.675
NEON	24.57	432.0	CARBON DIOXIDE	216.55	5,170.0
OXYGEN	54.36	1.52	WATER	273.16	6.105
NITROGEN	63.18	125.0			

R1M 92.0164.04

Figure 9. Vapor Pressure and Triple Point for Several GGSF Gases

2.5.6 Soots and Smokes

The requirements for this category of samples are listed in Table 21. The various design approaches for the generation of these samples and specific issues are discussed in section 4.2.6. It should be noted that the process by which the samples are generated, i.e., combustion, determines the size and quantity of the soot. There are very few controls that can be exercised to alter the process. It is not clear whether these "natural" processes are or are not compatible with the science requirements for the soot size and quantity.

A second issue is that moving these samples into the experiment chamber would probably require the use of a carrier gas which could interfere with the required chamber pressure and/or temperature. Further, in experiment 17, which has a preference of observing a single PAH molecule, the natural difficulties of locating and seeing this molecule are noted.

Table 21. Science Requirements for Combustion-Generated Soot or Other "Smokes"

Experiment No.	Materials	Size (μm)	Number Density (No./cc)	Pressure Range (bar)	Temperature Range, (K)
3	Soot	0.01 - 1.0	$1 - 10^4$	0.1 - 1.0	273 - 303
6	Soot from Acetylene and Liquid Fuels	0.1 - 10	100 - 1,000	0.5 - 1.0	293 - 303
13	MgO smoke	~ 1.0	10^5	0 - 1.0	77 - 300
17	PAH (Polycyclic Aromatic Hydrocarbons)	0.0005 - 0.01	1 or 10^{10}	$10^{-10} - 10^{-9}$	10 - 300
21	Soot	~ 0.1	$10^5 - 10^8$	1	298

2.5.7 *In situ* Generated Samples

The requirements for this group of experiments are listed in Table 22. The generation of particulate matter in the chamber via an external stimulation is required in these experiments. RF discharge (9), UV photolysis and or electrical discharge (14), and agglomeration in an electrical field (13) are specified.

Table 22. *In situ* Sample Generation Requirements

Exp. No.	Mechanism	Materials	Size (μm)	Number Density (No./cc)	Pressure Range (bar)	Temperature range (K)
9	RF discharge	CH_4, N_2 mix	< 1	TBD	$2x10^{-3}$	300
14	UV or E discharge	Organics: CH_4, N_2, H_2, tholins	0.005 - 10	$10^5 - 10^8$	0.001 - 1.0	200 - 300
13*	E-Field	MgO smoke, olivine, pyroxene	1	$10^6 - 10^8$	0 - 1	77 - 300

* Exp. 13 requires the use of an electric field for agglomeration; soot and smoke particles are injected into the chamber.

The UV radiation is typically provided by a UV source (special lamp) that can be transmitted into the chamber through UV-transmitting windows. The RF and electrical field sources are probably special accessories which will be inserted into the chamber. It is not clear whether it is possible to control the number concentration and size of these samples independently.

2.5.8 Low-Temperature Condensates

These requirements are for (1) the formation of ices of CH_4, NH_3, H_2O, and CO_2, or the coating of other particles with these ices, and (2) condensation of vapors into liquid droplets. They are summarized in Table 23.

This class of experiments generally requires the introduction of condensation nuclei on which the vapor condenses. Therefore, there is some overlap here with Table 18 for the solid particle dispersion. Experiment 16 is included in this table, although it requires the condensation of high-temperature vapors (of metals and silicates) onto which the ices are formed. This experiment is also included in Table 24 for the high-temperature condensates.

Table 23. Condensation of Vapor and Nucleation Requirements

Exp. No.	Nuclei Material	Condensate Materials	Size (μm)	Number Density (No./cc)	Pressure Range (bar)	Temperature Range (K)
1	Silicate grain	H_2O, CO_2, CH_4, NH_3	1 (grain), 1 mm to 1 cm aggregate	2 aggregates	10^{-3} - 10^{-6}	150
2	Silicates, tholins	H_2O	<10 to 1,000	2 particles	10^{-4} - 1	150 - 300
3	Salt, soot	H_2O	0.01 - 1.0 (nuclei) 1 to 20 (drop)	1 - 10^4	0.1 - 1.0	273- 303
6	Soot	H_2O	0.1 to 1.0	100 - 1,000	0.5 - 1.0	293 - 303
7	TBD	CO_2, CH_4, NH_3	0.1 - 100	4x10 to 40	0.03 - 3.0	80 - 300
8	Carbon	H_2O	0.1 (aerosol) 500 - 2000 (drop)	1000 (aerosol) 1 (drop)	10^{-4} - 1.0 (10)	233 - 293
16	Condensed metal silicates vapor	H_2O	20	10^8 to 10^{11}	1	4 - 300

Unlike some of the earlier experiments in which the particles would be injected into a cold chamber, here it may be desirable to inject the particles into a chamber at a temperature above the freezing point of the vapors. Otherwise, vapor would condense on walls before the particles are introduced. In general, since the walls present a much larger area than the surface of all the particles, there may be a significant amount of condensation and freezing on the wall rather than on the particles. Generally, the vapor near the wall condenses, creating in the process a concentration gradient that drives, by diffusion, more vapor toward the wall. Since the particles are scattered through the volume, they too are expected to serve as condensation nuclei. The balance between the wall condensation and the particle condensation must be considered, however, in the design of the experiments. As discussed earlier, the chamber cooling time must be considered relative to the characteristic sedimentation time (especially with the low-pressure experiments).

2.5.9 High-Temperature Condensates

The requirements for this class of experiments are listed in Table 24. These requirements relate to the formation of vapor of high-boiling-point substances, typically in an oven, and the condensation of the vapor in the experiment chamber. Thus a large temperature gradient is implied. For two of the experiments the condensation nuclei material is not stated. Therefore, it may be **assumed** that homogeneous nucleation is anticipated. Homogeneous nucleation can be reached by supercooling the vapor. In this particular case of high-temperature vapor, supercooling will occur very quickly anyway. The issue of wall condensation versus condensation in the volume or on the condensation nuclei is applicable in this case, too (see section 2.5.8).

As in some of the other sample formation processes (see discussion in section 2.5.6, Soots) it is not clear whether there is a way to exercise control over the number density and the size of the aerosol formed in this process. It may be that the experimenter will operate with whatever these parameters happen to be.

Table 24. Science Requirements for Aerosols Formation by Condensation

Exp. No.	Nuclei	Condensate Materials	Size (μm)	Number Density (No./cc)	Pressure Range (bar)	Temperature Range (K)
10	TBD	Bimetallic elements	1 - 100	TBD	TBD	TBD
15	Refractory oxides	Metal bearing gases (CaO, FeO, MnO, K_2O/Na_2O, NiO, metal-carbide, metal-hydrogen, etc.)	0.01 - 0.05	10^6 - 10^8	10^{-6} - 10^{-3}	500 - 1,200
16	TBD	Metals, silicates	~ 0.01	10^8 - 10^{11}	1	4 - 300

Technical Issues

- *Sample introduction for vacuum experiments with no carrier gas may be required for experiments 1, 3, 5, 8, 13, 15, 17.*
- *Some sample generation processes (e.g., soot generation by combustion, homogeneous condensation, in situ formation, etc.) produce characteristic particle size and concentration with little or no ability to control one or both parameters.*
- *For the very fine particles at very large number densities (e.g., experiments 3, 13, 15, 16, 17, 18), the coagulation and agglomeration happens on a time scale which is shorter than the dispersion process; it is not obvious whether the analytical tools exists, or how the initial concentration and size of the particles can be evaluated or measured. Possibly by fitting later-time measurements with appropriate model and extrapolating back to time = 0 would accomplish this.*
- *Experiments 1 and 7 wish to form CO_2 ice in the chamber which would require a special development.*
- *Experiments 1, 2, 4, and 12 require specific technique to form, position and manipulate a single drop or particle.*
- *The required residence time for the various experiments must be compared with the characteristic sedimentation and diffusion times.*

2.5.10 Sample Manipulation

Sample manipulation requirements include what the workshop questionnaire refers to as **levitation** and/or **positioning**, as well as **particle acceleration**.

A broad definition of **levitation** in the context of GGSF implies holding an object in a certain position against forces which otherwise would cause the object to move. Specifically, this refers to keeping the sample at the center of the experiment chamber, or away from the wall, against drift caused by residual gravity. Positioning means placing the sample at a specific position in the experiment chamber. Once positioned, the sample would move in accordance with the forces (e.g., residual gravity) acting on the sample. The answer found in the workshop questionnaire regarding the need for levitation was often a "yes" for experiments that involve either a single particle droplet or a cloud/aerosol.

Positioning was not specifically mentioned in the workshop questionnaire but is an implied requirement for the collision and the crystal-growth experiments (Exp. 1, 2, 4, and 12). For the former, the initial particles must be positioned and accelerated so that the interaction can be observed at a predicted location in the chamber. The particles to be positioned range from several μm (Exp. 2), to 3 cm (Exp. 4) for solid particles, and from 20 to 3,000 μm (Exp. 12) for a liquid drop.

The third type of sample manipulation requirement, as stated above, is to **accelerate particles** in order to effect a collision between two particles, or particles and a target (e.g., wall). The collision velocity, based on conversations with the experimenters, are in the range of a few cm/s. The particle size in these experiments, however, range from a 1 mm (and up to 1 cm) **aggregate** made of 1-μm particles (Exp. 1), 10- to 30-mm "**ice balls**" (Exp. 4), and up to 10- to 1,000-μm single **particles** (Exp. 2).

Analyses and trade-offs for these requirements can be found in section 4.4.

2.6 Diagnostics

The discussion of the diagnostics requirements includes the various necessary measurements for characterization of the samples and the experiment conditions and environments. The specific techniques and/or instruments mentioned by the various experimenters are listed in Table 25 and a summary of the measurements required by the experimenters is provided in Table 26. The major set of diagnostic techniques is related to optical measurements.

Table 25. Instruments, Techniques, and Light Sources Requested

Instruments/Techniques (Exp. No)	
Spectrophotometer (5)	Long-range microscope (8)
Nephelometer (5)	Spectrometer: 0.2 to 2.5 μm (9); 0.3 - 0.8 μm (10)
Photography/video (see Table 26)	Pulsed laser (HeNe or ruby) (10)
OPC (Optical Particle Counter) (6, 18)	15-channel PMS spectrometer (11)
Linear array detectors (7)	Gas chromatograph (11, 16)
OMA 0.5 - 1 nm resolution (16)	Monochromator: 100 - 200 nm (in the VUV) (17)
Monochromator, 100-1,000 nm (17)	NIR, MWIR and LWIR, LHe or LN2 cooled detectors (17)
Laser Doppler (13)	Stereo photography/video (1)
Polarization (7, 13)	FTIR (8, 9)
Light Sources	
Tungsten lamp - 1,000 watt (7)	White light for photography/video (several)
UV source, 180 - 300 nm (2, 13, 14)	Pulsed HeNe or ruby laser (10)
UV- Xe, 200 - 300 nm (11)	High-pressure Hg lamp + filter wheel (13)
Xe arc lamp 170 nm to 2 -3 μm (16)	H_2 lamp 10^{15} photons/cm^2-s flux (16)
HeNe laser, 10 mW (21)	

Table 26. Summary of Workshop Proposed Measurements Techniques

Measurement	Exp. no.
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 and scattering	5, 7, 9, 10, 15, 16, 21
Forward and 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 and relative particle motion	2, 4
Aggregate or 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 materials	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 or fill factor and mass	1
Particle rotation	4
Electrical charge	

In general, diagnostics are considered in three categories, as follows. In-line diagnostics are typically optical techniques that utilize spectral and spatial extinction properties of the particles for their characterization (e.g., scattering, transmission, etc.) Off-line technique extract samples into various instruments which utilize either optical properties or chemical/physical properties for the sample characterization (e.g., electrical mobility analyzer, condensation nuclei counter, etc.) In-chamber techniques are experiment-specific instruments that have to be placed inside the experiment chamber to perform the required characterization (e.g., measure particle charge, strength of fractal particles, and particle polarity, etc.)

2.6.1 In-line Diagnostics

Light extinction and/or scattering measurements, including angular scattering and spectral measurements, are required by 14 of the experiments. The size range of the particles for these experiments is depicted in Figure 10. **Angular** scattering measurement requirements are shown in Table 27. The scattering angle covers the range from 0° (forward scattering) to 180° (backward scattering). The **spectral** scattering covers the range from UV to IR, primarily in the range from 200 nm to 2.5 μm. Specific requests include, however, 100 nm to 3.0 μm (Exp. 16), although the principal range is from 200 to 700 nm. The range from 100 nm to 1000 μm (10 cm^{-1} specified by experimenter) is specified in one case (Exp. 17). FTIR is specified in two cases (Exp. 8, 9) with spectral range from 2 to 25 μm. **Polarization** sensitivity is specified in a couple of cases (Exp. 7, 13).

Over half of the experiments (12) require the measurement of size distribution of the sample materials in the chamber. Figure 11 summarizes the size range for these experiments, and Figure 12 relates the size concentration range for these experiments.

TECHNICAL ISSUES

- *Various ranges of "light" sources (UV - MWIR), both monochromatic and wideband, need access to the chamber.*
- *Chamber windows transmission efficiency for the broadband sources must be considered.*
- *Broad range of detectors for UV, VIS, NIR, MWIR must be considered.*
- *A combination of monochromators and filter wheels for the selection of wavelength is implied.*
- *Monochromators, spectrophotometers, spectrometers, and OMAs for transmitted beam spectral measurements require interchangeable diffraction gratings for the broad range of spectral requirements.*
- *Spectral resolution requirement should be specified for the transmitting or receiving optics.*

Table 27. Angular Scattering Measurements (0°-Forward, 180°-Backward)

Exp. No.	5	6	7	8	9	10	12	13	14	15	16	18	19	20	21
Angle, deg.	180	TBD	VAR[1]	TBD	VAR	TBD	TBD	90	VAR	TBD	90& 180	VAR	VAR	VAR	VAR

[1] VAR -- Variable Angle

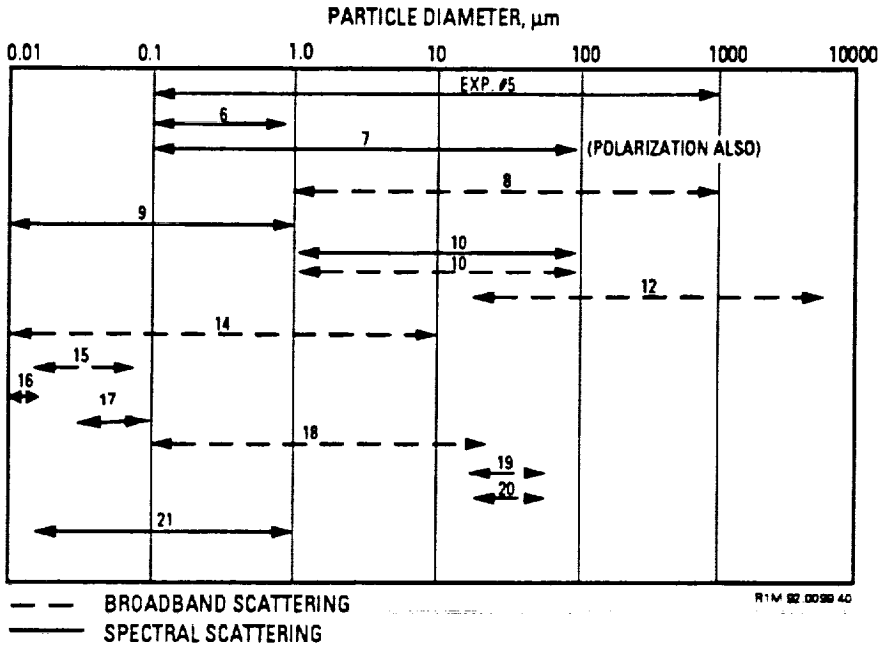


Figure 10. Particle Size Range in Scattering Measurements

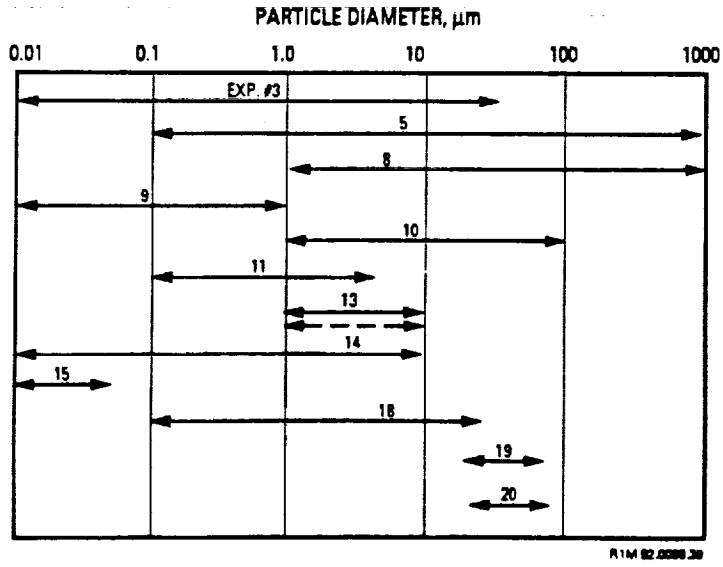


Figure 11. Sample Size Range for Experiments Requiring the Measurement of Particle Size Distribution

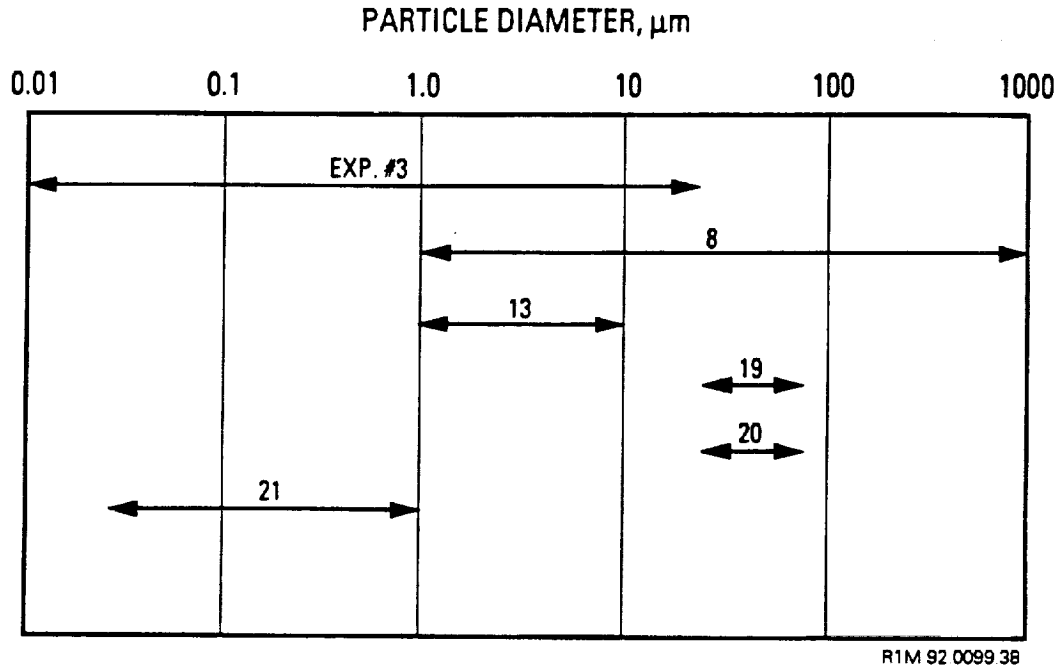


Figure 12. Sample Size Range for Experiments Requiring the Concentration Measurements

2.6.2 Imaging/Video

Imaging and or video requirements were specified for a number of experiments. The requirements, as listed in the workshop, and the update obtained in this study are summarized in Table 28. The particle size range for these experiments is shown in Figure 13. The requirements include high spatial resolution and high frame rate. It is believed that all experiments involving collisions (1, 2, 4) may require a frame rate higher than the standard RS-170 (30 fps). Spatial and temporal resolution for the experiments should be specified. For most experiments, however, it is possible that a single frame at very low frequency may suffice.

Table 28. Video Requirements

Req.	Video req.	Video Possibly Required	High Spatial Resolution	High Frame Rate	Stereo	No Video Required
Exp. No.	1, 2, 4, 5, 7, 8, 9, 14, 15, 16, 18	3, 11, 12, 13, 17, 19, 20	2, 5, 8, 16	1, 2, 4	1	6, 10, 21

TECHNICAL ISSUES

- *Requirements for the spatial and temporal resolution need to be more specific (i.e., observation of single particles or of overall cloud) including: frame rate, duration, frequency.*
- *The requirements for FOV and depth of field must be specified.*
- *Experiments 1, 2, and 4 may require a high-frame-rate video.*

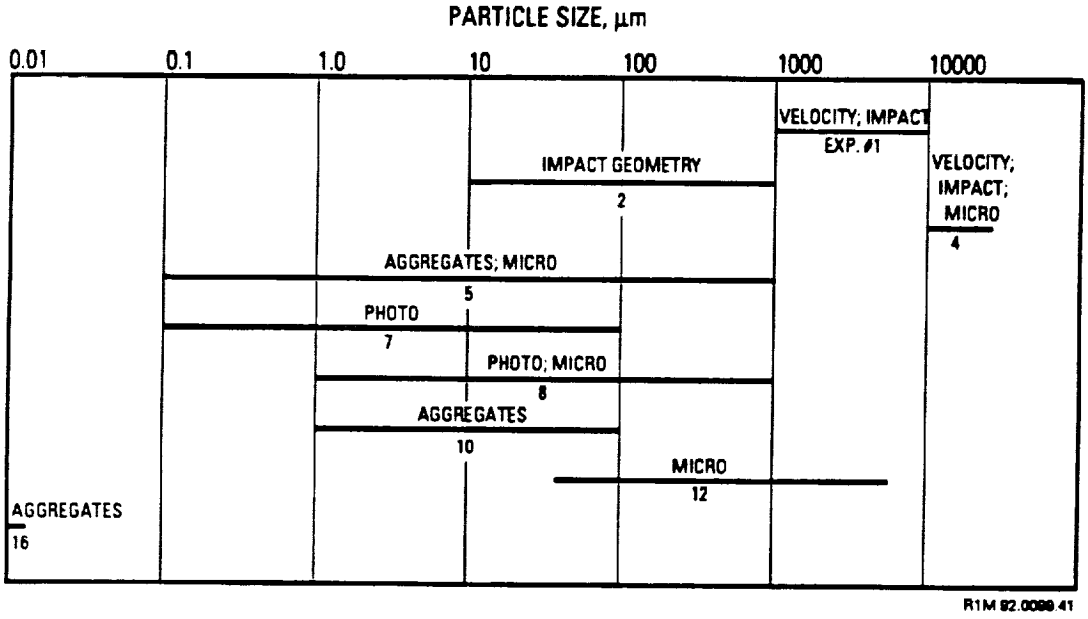


Figure 13. Sample Size Range for Imaging

2.6.3 Off-Line Diagnostics

Off-line diagnostics include certain optical particle counters (OPC) (Exp. 6), condensation nuclei counter (CNC) (Exp. 21, 6), and other systems that require the removal of samples from the test chamber by a carrier gas stream. The use of an off-line system implies requirements for a sample removal port, sampling probe, and perhaps a dilution air stream, depending on the type of counter.

2.6.4 Other Experiment-Unique Diagnostics

The diagnostics which seem to be experiment unique include:

- Determination of the electrostatic charge of a particle (Exp. 5)
- Determination of mass and density of agglomerates (Exp. 1)
- Analyses using HPLC (Exp. 11)
- Fractal shear strength determination using ultrasound (Exp. 16)
- Count of organism number in a droplet (Exp. 19, 20)
- Analysis using SEM, TEOM (Exp. 21)
- FTIR (Exp. 8, 9).

2.6.5 g-Level

Experiments 11 and 16 required g-level of 10^{-5}. Other experiments may like to obtain measurements of the g-level. Since the lowest possible g-level on board is expected to be no better than 10^{-6}g, this may set the required sensitivity level of the measurement. The accuracy of the g-level measurement requirements specified are shown in Table 29.

Table 29. g-level Measurement Accuracy

0.001g (Exp. 8)	±10% (Exp. 16, 21)	±1% (Exp. 15)

2.6.6 In-Chamber Operations and Tests

Certain proposed experiments require in-process tests or activities. The type of activities that have been identified are as follows:

- Charging of a particle (Exp. 2, 3)
- Injection of a gas or vapor (Exp. 6, 16, 18)
- UV illumination of particle cloud (Exp. 11)
- Removal of aerosol for biological analysis (Exp. 19, 20)
- Application of an electric or acoustic field (Exp. 8, 13, 16)
- Manipulation of particles through a thermophoretic collection grid (Exp. 21).

Except for the gas injection, these activities are experiment-specific.

2.6.7 Pressure and Temperature Diagnostics

Pressure and temperature measurements are part of the diagnostics system. However, these diagnostics are integrated into the chamber and therefore are separately discussed in section 2.4, Experiment Environment.

2.7 Experiment Operations

In most cases the experiments may be affected one way or another by induced environments such as vibration (due to g-jitter), turbulence (generated by the introduction of particles), electrostatic charges (typically found on most small particles/droplets), electrostatic fields (levitation system), acoustic fields (low-frequency vibrations, or levitation systems), etc. The importance of such induced environments to each experiment should be assessed since they may affect the experiment timeline as well as experimental methods. The workshop questionnaire collected qualitative information to that effect from the experimenters. Table 30 represents an attempt to quantify the information, based on a subjective reading of the answers in the questionnaire.

2.7.1 Experiment Control Requirements

This section summarizes the requirements of real-time experiment monitoring and control, up/down link, and on-board data processing. Table 31 attempts to quantify the qualitative requirements expressed by the experimenters in the workshop questionnaire. Most experimenters also felt that a micro computer is all that is required for the task. Experiments 16 and 21 mention minicomputer, and experiment 17 mentioned a micro- or minicomputer for a part of the experiment and a "big one" (implying a mainframe computer) for performing the whole experiment. We recommend more detailed experiment time lines be generated to aid the assessment of experiment control requirements.

TECHNICAL ISSUES

- *Computer functional requirements will have to be determined on the basis of detailed time-lines for the experiments including experiment control functions, communications, and data storage requirements.*

2.7.2 Experiment Duration and Number of Repeats

The minimum/maximum experiment duration as estimated by the experimenters are shown in tabular form in Table 32 and graphically in Figure 14.

Table 30. Environment Effects on Experiments

EXP. NO.	BROWNIAN MOTION	TURBULENCE	VIBRATIONS	ELECTRICAL MAGNETIC FIELDS	ACOUSTIC	ELECTRICAL CHARGE	RADIATION FORCE	RADIATION PRESSURE	DIFFUSION
1	2	1	2	5	1	4	1	1	1
2	3	2	2	3	4	4	4	4	4
3	1	4	1	1	1	1	1	1	4
4	1	1	1	1	1	1	1	1	1
5	4	4	1	4*	4*	4	5	5	5
6	1	1	5	1	1	1	1	1	1
7	1	1	4	3	5	3	5	5	5
8	4	4	5	4	5	4	4	4	4
9	NS	NS	NS	NS	NS	NS	NS	NS	NS
10	NS	NS	NS	NS	NS	NS	NS	NS	4, 5
11	2	4	3, 4	1	1	4	5	5	4
12	NS	4	4, 5	1	3, 4	1	1	1	5
13	5	2	2	4	1	4	2	2	2, 3
14	4	5	NS	1	5	4, 5	5	5	4
15	5	4	5	5, 1	5	5	5	5	4
16	5	5	5	5	5	5	5	5	5
17	1	1	1	1	1	5	5	3	1
18	4, 5	4	1	4	1	4	1	1	4, 5
19	1	1	1	1	4, 5	1, 5	4	4	5
20	1	1	1	1	4	1, 5	4	4	1
21	4	5	5	5	5	5	5	5	4

Key

1: Insignificant not applicable. 2: Slight minimize or avoid if possible. 3: O.K. or neutral. 4: Affects experiment (desired or undesired effect). 5: Unknown, more studies needed. *: detrimental. NS: Not specified.

Table 31. Experiment Control Requirements

Exp. No.	Real-Time Data Downlink	Real-time Data Processing/ Analysis On-Board	Real-Time In-Flight Analysis by the Experimenter	Required Interaction Between Experimenter and Experiment
1	1	1	1	1
2	3	2	1	0
3	3	2	2	2
4	2	2	1	2
5	3	1		1
6	1	1	0	0
7	2	0	0	0
8	1	0	1	0
9	1		1	0
10				
11	1	2	0	0
12	1	0	0	1
13	1	0	1	1
14	1	1	0	0
15	1	1	1	0
16	2	2	2	2
17	2	2	1	2
18	1	1	1	1
19	1	1	2	
20	1	1	2	
21	1	0	0	2
key	1 = only store data 2 = possible 3 = definitely	0 = none 1 = control experiment 2 = data reduction	0 = no 1 = some 2 = a lot	0 = no 1 = only post-experiment 2 = real time

Table 32. Individual Experiment Duration and Number of Repeats

Exp. No.	Duration	No. of Repeats	Exp. No.	Duration	No. of Repeats	Exp. No.	Duration	No. of Repeats
1	10 - 100 sec	100 - 1,000	8	hrs. to days	NS	15	< 1 wk	NS
2	10 min	100s	9	1 to several wks	NS	16	hrs. to wks	NS(9 - 45)
3	10 min - 1 day	NS	10	NS	NS	17	NS	NS
4	1 - 10^4 sec	100s	11	> 4 wks	NS	18	hrs	~ 100
5	min to days	< 100	12	12 - 24 hrs	10	19	< 10 days	NS
6	100 - 10,000 sec	NS	13	4 - 5 hrs	NS	20	< 10 days	NS
7	<1 day	NS	14	3 - 4 wks	NS	21	1 day to 2 wks	NS

NS: Not specified.
[1 hr = 3,600 s, 24 hr = 86,400 s; 1 wk = 604,800 s; 1 month (4.3 wk) = 2,600,640 s]

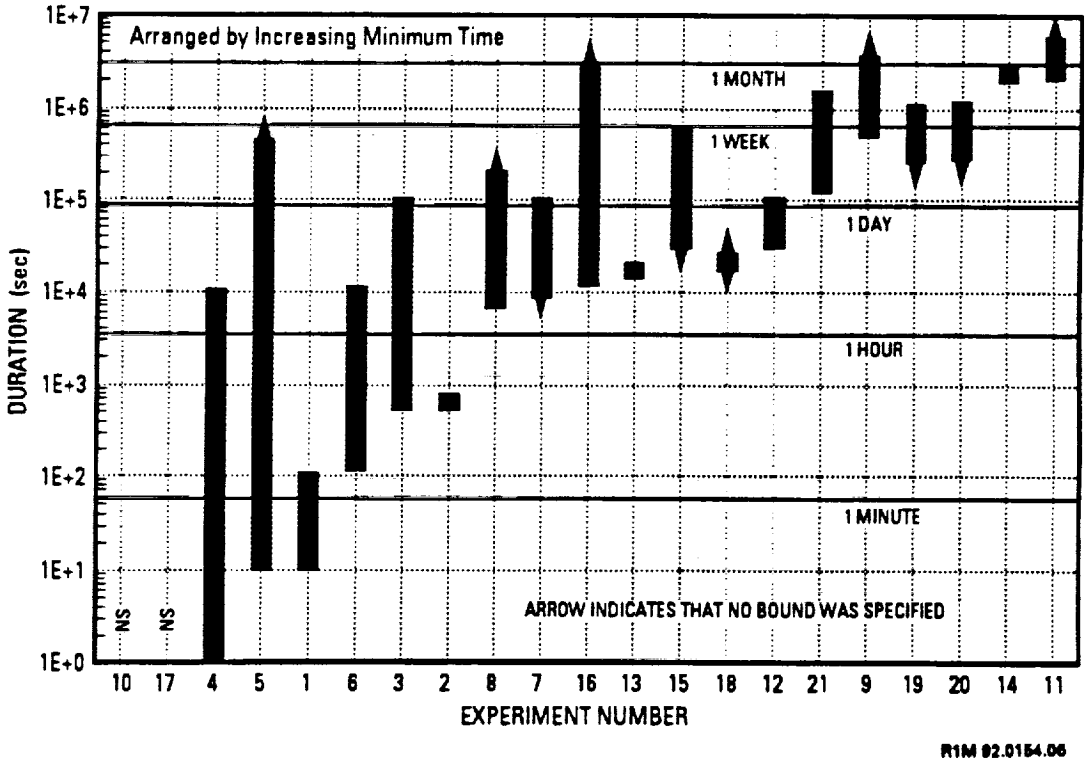


Figure 14. Experiment Duration

3 SPACE STATION ENVIRONMENT AND ACCOMMODATION

The SSF has undergone a number of major design changes in the past couple of years and many of the formal documents became obsolete while new documents are as yet unavailable. At the time this report was prepared, the SSF was at the PDR level. TRW attempted to receive and utilize the latest documentation (in some cases not yet approved), or even Working Group Meeting Minutes and personal communications with the SSF contractors, NASA/JSC, MSFC, and the SSF library in Reston. Nevertheless, SSF will continue to evolve and information will have to be updated as the GGSF project proceeds. At the time of release of this document some of the references noted within are obsolete yet the conclusions of the report have not been affected.

This section discusses the U.S. Laboratory Module accommodations as applicable to the GGSF only. General information on SSF and the U.S. Module can be found in the references. Top-level payload interface requirements will ultimately be governed by two key documents, which are not yet released: the Payload Accommodation Handbook and the Integration Requirements on Payloads.

Several other documents are referenced in this section as appropriate. There are over two dozen other interface documents that describe the details of SSF interfaces to the U.S. Module payloads. These documents will be needed to do the Phase C/D design work, but are not needed for the Phase A or B studies.

In general the U.S. module will carry 12 user racks out of a total of 24 racks. With a few exceptions, discussed below, these racks are identical and provide the same utilities. A U.S. module configuration is shown in Figure 15. The figure shows a pivot point for all the racks, which means that each rack must be built such that it can be rotated to allow access to the module wall for maintenance. A cross section of the module with the racks in, or out of, position is shown in Figure 16. The stand-off regions between the racks (labeled x1 - x4 in Figure 16) in the module provide the various interfaces and utilities, including cabling, N_2 gas, avionics air, vacuum line, waste line, power, etc.

3.1 Environment

3.1.1 G-Level

The g-level is affected by two major factors. First, the SSF orbits at an altitude at which the atmosphere is very thin. This atmosphere creates aerodynamic drag which causes the SSF to decelerate. Second, only the center of gravity (c.g.) would experience a true 0-g environment. As the distance from the c.g. increases in the direction normal to the velocity vector (i.e., along the nadir), the gravity gradient equates to an increase in the g-level. The above effects create the residual gravity (DC) component, which is typically expected to be about 10^{-6}g.

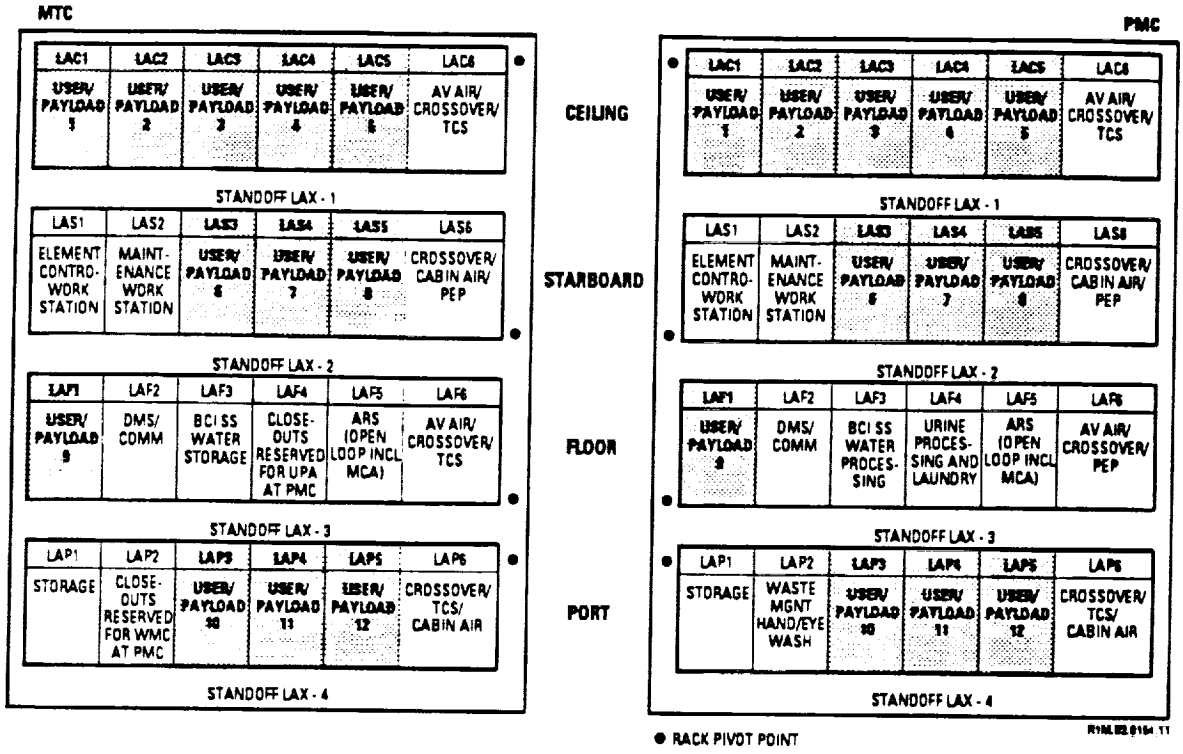


Figure 15. U.S. Module Configuration

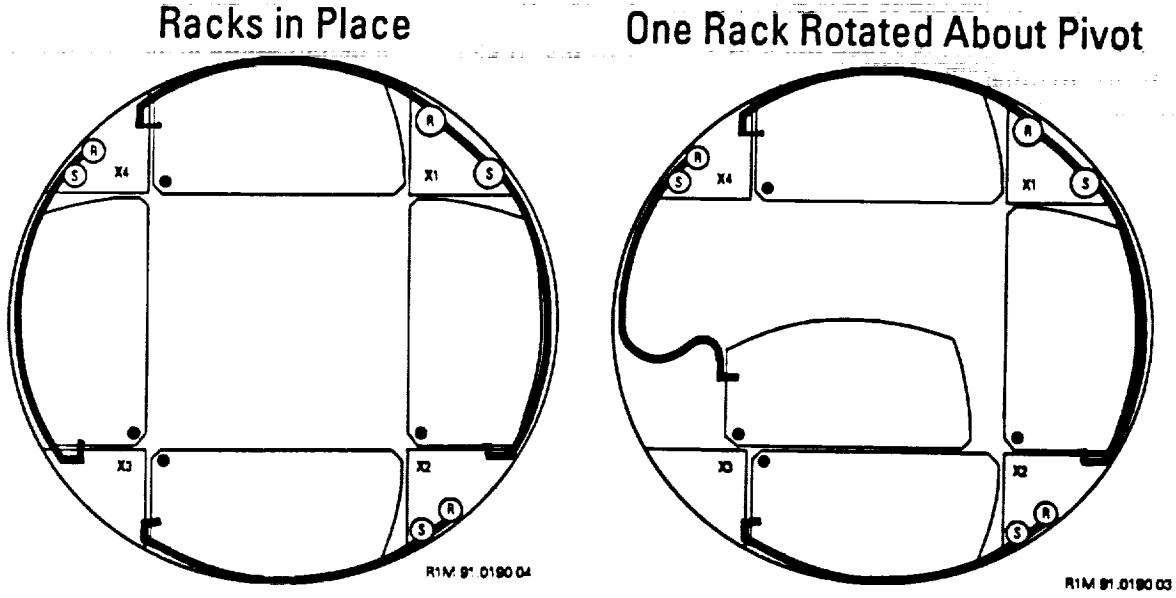


Figure 16. Cross-Section View Through Module

In addition to the DC level, there are considerable vibrations at frequencies covering a broad spectrum. These contribute to the AC component of the acceleration. The vibrations may be induced by firing the SSF's thrusters for various reorientation maneuvers, by manned activities on board, machinery, etc., and are usually referred to as g-jitter. Various models have been developed for the expected g-level and vibrations on board SSF. One such model is shown in Figure 17. Other disturbance details are given in the references.[5]

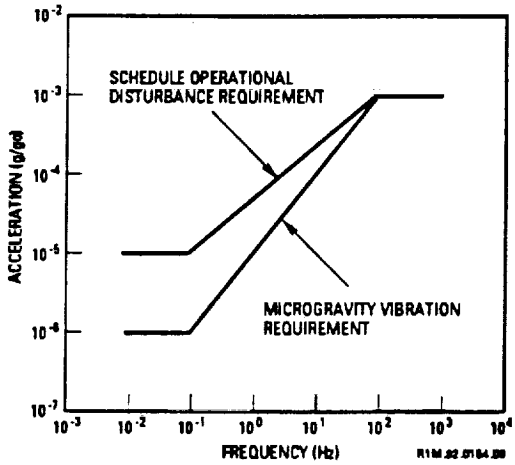


Figure 17. A g-Level Model for SSF

The DC and the AC components of the acceleration have a different impact on the GGSF experiments. The DC component causes the experiment sample to "fall" in the direction of the resultant g-vector. Since the chamber size is finite, the samples essentially impact the chamber wall. The time available for an experiment depends, therefore, on the chamber size, the pressure, and the particle size. A detailed analysis is given in section 4.4.1 and Appendix E. The only way to mitigate this effect is through experiment design that takes into consideration the necessary effects.

The AC component is manifested as vibrations. The very high frequencies are not coupled mechanically to the heavy hardware and cause little interference with the experiment. The lower frequencies, however, may cause some interference with the experiment. First, these vibrations may cause the experiment chamber to vibrate (depending on the vibration isolation and mechanical mounting of the chamber) creating an acoustic wave pattern inside the chamber. It is anticipated that the acoustic energy coupling impedance mismatch is fairly high and the amount of energy transfer to the gas is minimal. The gas motion, as small as it may be, could nevertheless, have an effect which is of the order of magnitude of some of the other forces under investigation (e.g., van der Waals) and interfere with delicate particle coagulation, agglomeration, and perhaps cause breakup of some fragile structure (e.g., fractals). A second effect of the AC component may be manifested in the imaging and diagnostics. Specifically, when the cameras are focused on small particles, thus having a very shallow depth of field, any vibrations may cause the particle image to blur or totally disappear.

[5] SS-HDBK-0001, Vol. 1, Section 7, and SSP-41017.

To mitigate these effects, the mechanical coupling of the low-frequency g-jitter with the chamber will have to be carefully analyzed. Similarly, the internal acoustic effect will have to be analyzed and compared with the magnitude of the other forces of interest to the experiments. Finally, the approach to mounting of the optical equipment to the chamber has to consider this effect as well.

3.1.2 Pressure and Temperature

At MTC the laboratory atmosphere is ~0.0704 MPa (10.2 ±0.6 psia), at PMC it is 0.101 MPa (14.7 ±0.2 psia). All payloads should be designed for a maximum pressure of 0.11 MPa (16 psia). At MTC at low ambient pressure the oxygen content in the module may be up to 30% (as compared with 21% at standard atmosphere). This imposes a severe flammability requirement and restriction on the use of certain nonmetallic materials.

Temperature: TBD

3.2 Physical Accommodations

Payload accommodation is based on the International Standard Payload Rack (ISPR) which is a standard collectively agreed upon by the international partners to the SSF. The rack is user-supplied based on the standard design (Boeing may be a supplier of the ISPR). The ISPR is shown in Figure 18 and some features are given in Table 33.

The ISPR has an upper and lower side access panels and a center rear panel. All panels and faceplates may be removed and replaced by user-provided panels that meet applicable requirements. EMI bonding grounding shall be a permanent part of any such outfitted rack.[6]

3.3 Utilities

A schematic of the utility interfaces is shown in Figure 19. A brief discussion is provided in the following subsections.

3.3.1 Cooling Water

Cooling water will be available to act as a heat sink on the cold side of a heat exchanger. The payload will have a choice of two cooling water inlets:

1. Nonselectable inlet minimum inlet temperature of 16°C and maximum outlet temperature of 50°C. At 6-kWe power locations the flow is 190 kg/hr; at the 3-kWe power location the flow rate is 130 kg/hr.
2. Low-temperature coolant water at a nonselectable inlet temperature of 0.5 to 10°C.

[6] SSP 41002 provides more information on the ISPR.

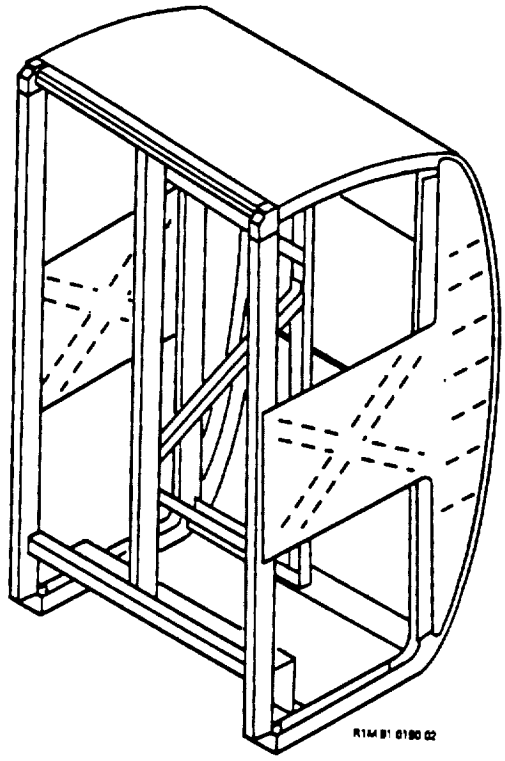


Figure 18. ISPR

Table 33. ISPR Features[1]

Physical dimensions	2 side-by-side 19" racks per EIA RS-310-C Maximum depth 75 cm, height 164 cm, width 93 cm
Payload volume	~1.13 m^3 out of 1.55 m^3 total
Miscellaneous	Fire suppression system using CO_2
Configuration	4- or 6-post racks available
Weight capacity	4-post rack weighs ~ 58.5 kg, supports 700 kg 6-post rack weighs ~ 68.2 kg, supports 700 kg Structural augmentation is required for payloads > 400 kg for stiffness.
Construction	Composite (graphite/epoxy)
Electrical power	3 to 6 kW, depending on the location
GN_2 Supply	Through a 3/8-inch line at a pressure between 90 and 110 psia (0.621 to 0.759 MPa)
Vacuum exhaust	Waste management under strict control of allowable waste gases and contaminants
Vacuum vent	Provide vacuum down to about 10^{-6} bar
Avionics air	About 1 kW cooling capacity
Cooling water	Two loops of cooling water, one at a low temperature
Communications	Communications interfaces via a MIL-STD-1553 and an FDDI buses

[1] Based on NASA/ESA/NASDA agreement, amended. Payload interchangeability. Undated.

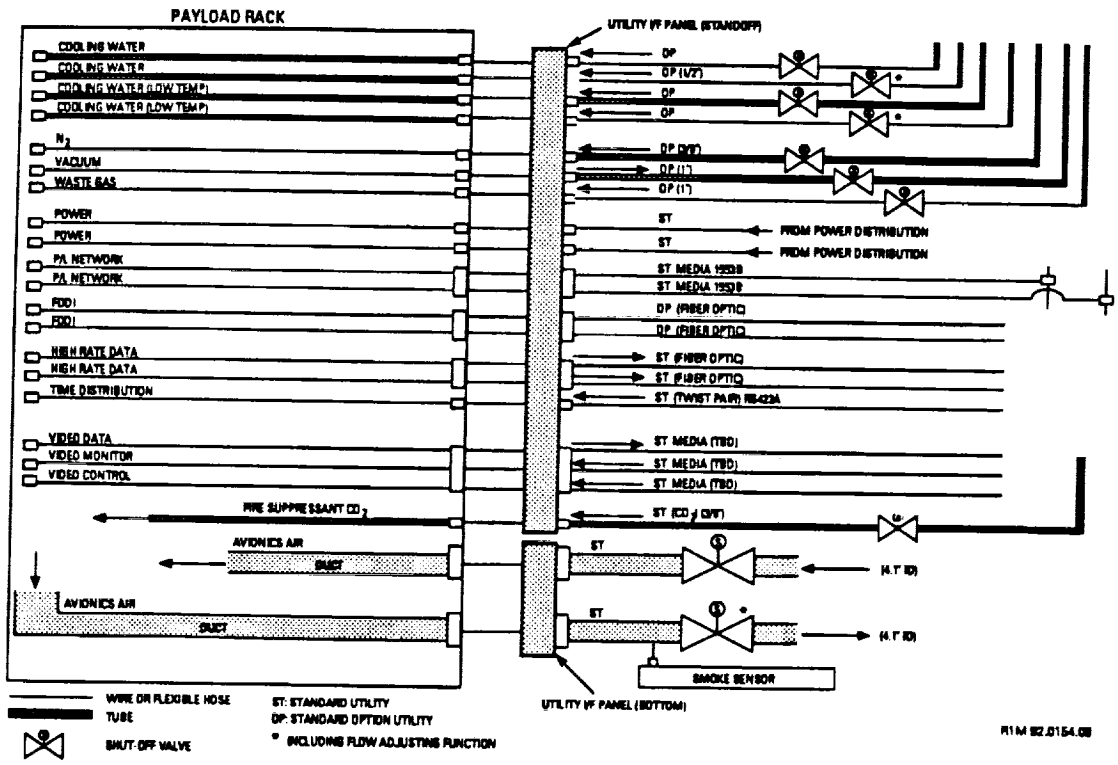


Figure 19. Utility Interfaces

3.3.2 Avionics Air

The total avionics air cooling capability is as follows:

- At MTC 830 watts per user rack, with a total of 2,500 watts for the 12 racks[7]
- At PMC 1,200 watts per user rack maximum, with a total of 3,600 watts for the 12 racks
- A minimum of 5 cfm (0.1416 m^3) air flow which equates to about 200 watts of cooling is required at all times for fire detection (the 200 watts comes from the user's allocation)
- Avionics air inlet temperature is between 17 and 25°C (nonselectable)
- Maximum allowable outlet temperature is 43°C.

3.3.3 Payload Venting; Vacuum and Waste Gas Lines[8]

The **vacuum exhaust subsystem (VES)** serves as a roughing vacuum system for pump-down of a payload from a maximum pressure of 40 psia to 1.0×10^{-3} torr. The VES is rated for a throughput of 2.5×10^{-3} torr-liter/sec at 1×10^{-3} torr (reference nitrogen at 72°F).

The **vacuum resources subsystem (VRS)** vents to external vacuum (1×10^{-3} torr, or 1.32×10^{-6} bar) with a throughput of 2.5×10^{-3} torr-liter/sec at 1×10^{-3} torr.

Both the VES and VRS interface at each ISPR.

The venting requirements[9] specify contamination control, limits on venting different elements, and verification requirements. The Payload Accommodation Handbook will be the reference for

[7] Rack Technical Interchange Meeting (TIM) Level II responses to user questions. Huntsville, July 1991. Documented by Dan Thomas.

[8] B. Adair. MSFC presentation material, Space Station Freedom Payload Venting, Feb. 10, 1992

[9] SSP 30426, Rev. B., July 1991.

all the requirements. Figures 20 and 21 summarize the VES allowable waste gases and contaminants.

AIR	✔
ARGON	✔
CARBON DIOXIDE	PARTIAL PRESSURE LESS THAN 3 torr AT ATMOSPHERIC PRESSURE
HELIUM	✔
KRYPTON	✔
NITROGEN	✔
XENON	✔
MIXTURE OF THESE GASES	✔
LIMITED AMOUNTS OF OXYGEN	PARTIAL PRESSURE LESS THAN 175 torr AT ATMOSPHERIC PRESSURE
LIMITED AMOUNTS OF HYDROGEN	PARTIAL PRESSURE LESS THAN 25 torr AT ATMOSPHERIC PRESSURE

R1M 92.0099 70

Figure 20. VES Allowable Waste Gases

CONTAMINANT	PPM (MAXIMUM BY VOLUME)
ORGANIC ACIDS INORGANIC ACIDS	5 5
ORGANIC BASES AMMONIA INORGANIC ACIDS	5 5 5
HALOGENS (Cl_2, F_2, Br_2, I_2)	5
PARTICULATES (> 10 MICRONS)	5
ORGANIC GASES ORGANIC SOLVENTS (ORGANOHALLIDES HYDROCARBONS, AROMATIC HYDROCARBONS, ALCOHOLS, ETHERS, ESTERS, KETONES, ALDEHYDES, AMIDES, THIOLS, SULFIDES, NITRITES)	5 5
SPECIFIC INORGANIC MATERIALS (HYDROGEN SULFIDE, SULFUR DIOXIDE, MERCURY)	5
SPECIFIC ORGANIC MATERIALS (FORMALDEHYDE, BENZENE, HYDROGEN CYANIDE, CARBON MONOXIDE)	5

USERS MAY BE FURTHER LIMITED IN WHAT CONTAMINANTS CAN BE VENTED WITH THEIR WASTE GAS ACCORDING TO EXTERNAL CONTAMINATION RESTRICTIONS

R1M.92.0164.10

Figure 21. VES Allowable Contaminants

External Contamination Restrictions and Contamination Control Plan. In addition to the venting requirements other requirements may influence the GGSF overall waste/contamination management plans. A program-level Space Station Freedom Program (SSFP) Contamination Control Plan will be generated in the future and will allocate limits on contamination level for program participants. In general, all areas considered as contamination sources while in orbit will

be controlled per the appropriate documents[10] and outgassing characteristics apply to all materials exposed to space vacuum.[11]

The requirements also differentiate between quiescent and nonquiescent (i.e., shuttle docking) time. During quiescent periods the external molecular column density due to all sources along any line of sight is limited to $1x10^{14}$ molecules-cm^{-2}. This limit may be exceeded within 1 meter of the vent axis. Particulates release is limited to one particle 100 μm or larger per orbit per $1x10^{-5}$ steradians field of view as seen by a 1-meter-diameter aperture telescope. In addition, to control the molecular deposition, the flux of molecules emanating shall be limited such that the 300 K mass deposition rate on sampling surfaces shall be limited to $1x10^{-14}$ g-cm^{-2}-sec^{-1} (daily average). During nonquiescent periods the restriction for molecular deposition and particulate release is reduced to $1x10^{-6}$ g-cm^{-2}-yr^{-1}.

Verification will be based on analytical models which the user may have to provide to SSF Level II.

3.3.4 Integrated Nitrogen Subsystem (INS)

GN_2 is provided through a 3/8-inch line at an interface pressure between 0.621 MPa to 0.759 MPa (90 to 110 psia). The GN_2 source is LN_2 and is 99.9% pure.

3.3.5 Power

Six ISPR locations have 3-kW, and six locations have 6-kW electrical power. Power distribution is at 120 Vdc nominal. The voltage range is from 120 to 126 Vdc with maximum ripple voltage 3 V peak-to-peak[12].

3.3.6 Fire Suppression

One CO_2 gas line is provided at each ISPR location for centralized fire suppression. CO_2 release will occur when the smoke detector detects smoke in the avionics air return line.

3.4 Data Management And Control

The details of the SSF Data Management System (DMS) are specified in NASA documents[13].

SSF provides the following capabilities at MTC:

- Payload FDDI network communication
- Payload local bus communication, MIL-STD-1553
- Time distribution bus
- High rate link and manual patch panel, providing Ku-band telemetry downlink
- Payload FDDI access to Ku-band telemetry downlink
- Disc (mass storage unit) storage of payload loads and critical data
- Video display support
- Payload FDDI MDM (multiplexer/demultiplexer)
- Payload data processor at PMC.

[10] JSC SN-C-0005, Contamination Control Document for the Space Shuttle Program.

[11] SSP 30233, Space Station Requirements for Material and Processes.

[12] SSP 30482 and SSP 30263.

[13] SSP 30261, Sections 1 through 4, (each section has a different update date).

The payload Interface Requirements Document (IRD) and the Integrated Flight Software Architecture Requirements are in preparation. Several comments are in place:

- The mass storage unit (MSU) is designed for software and critical operations. It is **NOT** intended for storage of payload science data.[14]
- The recommendation for payload data storage is the use of a payload-provided MSU.
- There is not as yet a standardized approach to payload development engineering (software and hardware). However, because of the potential benefits (listed below) to the SSFP there is a move in this direction.
  - Commonality between payload exists in the control of experiment environment
  - Instrumentation for data acquisition
  - Telemetry to ground
  - Common software libraries.

The Payload Development System (PDS) is based on the 80386-based PC workstation, including interface cards for FDDI, MIL-STD-1553, SCSI, and Payload FDDI MDM providing experiment environment control, data gathering, telemetry, and command and control.

3.5 Laboratory Support Equipment

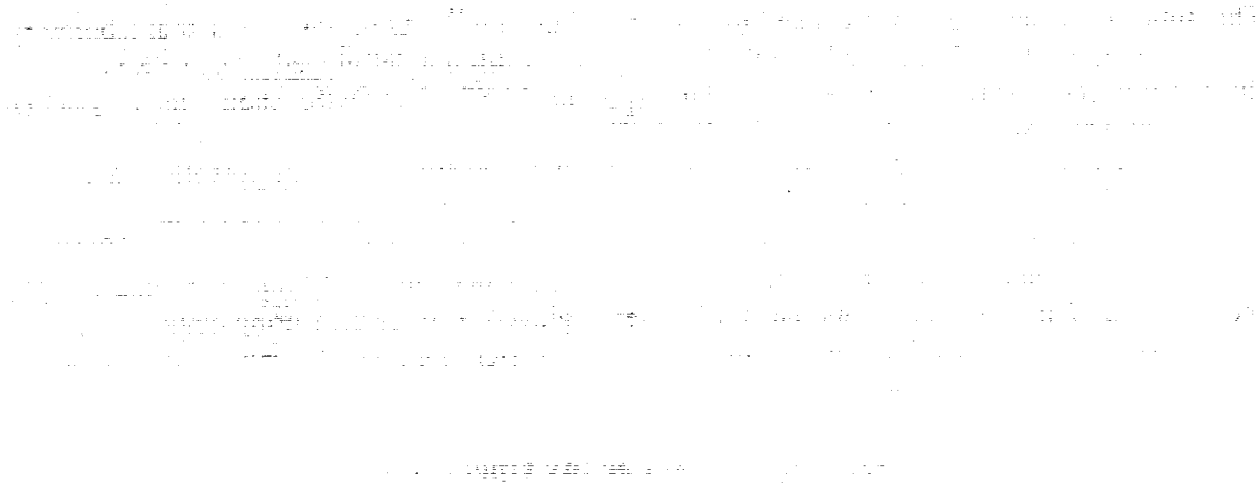
This subject is discussed in some detail in a recent publication[15]. As of now, the actual laboratory support equipment (LSE) available on the U.S. module is still not definitized. The LSE is divided into station-provided core LSE and user-provided LSE. The GGSF should identify actual equipment which will be of direct use for the experimenters and that could alleviate the functional requirements of the GGSF. A preliminary list of available LSE of potential use has been identified, including, for example, camera, autoclave, cleaning equipment, digital multimeter, EM shielded locker, film locker, fluid handling tools, freeze drier, freezer (-70°C), gas chromatograph and mass spectrometer, general purpose hand tools, HP liquid chromatograph, incubator, laboratory/science workbench, life science glovebox, mass measuring device, microgravity science glovebox, microscope system, pH meter, portable glovebox, refrigerator, specimen labeling device, and spectrophotometer.

3.6 Logistics of Facility Operations

During MTC, the shuttle docks every 90 to 180 days, for a few days. During that time the astronauts must perform any required maintenance operation. These occasions will also be used for hardware reconfiguration and replenishment of consumables as required. Due to such activities this is a nonquiescent time and must be considered whether experiments are affected by the induced environments. Because of their assignments to such activities, it is unclear how much time the astronauts will actually have to dedicate to operating the facility and conducting experiments. The quiescent environment between such shuttle docking provides a better experiment environment. During the quiescent period there is no operator to operate the payload and full automation or remote control is required.

[14] V. Whitelaw, Presentation to the SSSAAS DMS Status (pg. 16), NASA Level II Engineering Integration Office, Feb. 1992.

[15] U.S. Users Space Station Freedom Laboratory Support Equipment/ General Laboratory Support Facilities, Level III Requirements Document. Oct. 1991. MSFC JA01-001 (Draft).



4 FACILITY FUNCTIONAL REQUIREMENTS: TRADE-OFFS, ANALYSES, AND EVALUATION

The breakdown of the GGSF system into subsystems and the assignment of the functional requirements to those subsystems is an iterative process. The subsystem definition, somewhat arbitrary, should nevertheless have a logical breakdown so that all the science and technical requirements are properly assigned. The results of the iterations process are presented in this section.

The GGSF functional requirements were **derived** based on the thorough review of the experiments, the experiment Database and the requirements discussion in section 2 of this report. Common functions were collected into major subsystems. These functions correspond to the major subsystems of the GGSF, and are listed in section 1, Table 3. Figure 1 shows a block diagram of the functional flow within the GGSF, the major interfaces to the U.S. Laboratory Module and the SSF. A summary of the requirements is given in Table 3, while the supporting analyses establishing **derived** requirements are presented in this section. In the subsections that follow the science, mission, and functional requirements are reviewed, and the rationale for the specific approaches is traced. The review is conducted by subsystem in order to consolidate all the relevant information in an orderly fashion.

4.1 Chamber

Although the intent of this section is to analyze the chamber requirements, the interdependencies between the chamber concept and many other considerations necessitate a broad discussion of several related issues. The section below touches upon many of the issues that affect the chamber concept such as temperature and cooling, pressure and pumping, particle dynamics, etc.

4.1.1 Summary of Chamber Science and Technical Requirements

A brief summary of the chamber S&T requirements is shown in Table 34. In the sections which follow, these requirements are analyzed in terms of compatibility with other requirements, with the SSF accommodations, their impact on other requirements, and similar interdependencies.

Table 34. Summary of Chamber S&T Requirements

(Operating Conditions)

Volume, cm^3		Temp, K		Pressure, bar		Exp. Duration,			
1 to $>10^6$ (10^7)		(4) 10 - 1200		10^{-10} - 3 (11)		1 sec - weeks			
(Interfaces)									
Gas Fill, and Vent	Instru-mentation	Optical Windows	Internal Acces-sories	High vacuum	Cryo-cooler	Heater and Electrical Power	Sample Insertion	Sample Removal	Data Signal

( ) Number in parenthesis indicate an S&T goal expressed by the experimenter, not a requirement.

4.1.2 Analyses of S&T Requirements

The purpose of the following subsections is to analyze the requirements in light of possible design solutions.

4.1.2.1 Operating Temperature, Cooling Power, and Time Considerations

A brief review of the cryocooler technology is provided in Appendix C. A review of the chamber cooling characteristics is given in Appendix B. In brief, without the use of cryogenic liquids, which are **assumed** to be unallowed on board, the GGSF designer has to consider some difficult trades. The cool-down time, thermal mass of the chamber, chamber size, material selection, cooler power and the associated cooler mass, volume, and weight are all part of the equation that determines the thermal performance of the system. These selections have an additional ripple effect throughout the other GGSF subsystems. The reader is referred to the appendices and, in particular, to the summary and conclusions at the end of Appendix B.

Perhaps the major lesson of the analysis in Appendix B is that reaching low operating temperatures is not so much a function of the cooling power, as it is a function of the system design and the control of thermal heat loads. If thermal loads were kept to, say, 1/4-watt, then a 1/2-watt cooler should be sufficient. But these thermal loads increase with the size of the chamber that must be cooled, and 1/4-watt losses are unrealistically small. The conductive/radiative loads through the wall increase as the surface area of the chamber, i.e., in proportion to the diameter square. Radiative loads through windows are proportional to the surface area of these windows. Flanges, feedthroughs, and other connections for sensors and gas lines increase the conductive loads significantly, and, therefore, should be carefully designed.

Material selection is important in providing a uniformly cooled chamber. However, material properties may prevent the use of the same chamber for cryocooling as well as for the high temperature range. For instance, to minimize the thermal gradients in the chamber wall during cooling, a material with good thermal conductivity is required. Aluminum or copper seem to be possible choices. These materials are inappropriate for the high-temperature chamber (1,200 K), though, which may require inconel or equivalent materials.

GGSF FUNCTIONS SUMMARY

Based on thermal considerations a small chamber is required for all low-temperature experiments. The large chamber is to be used only to meet high-volume requirements if the temperature penalty is acceptable.

Material selection must include considerations such as thermal cooling and temperature uniformity, and considerations related to the catalytic effects of wall materials.

4.1.2.2 Pressure Operating Range

The pressure performance of the chamber covers a wide range of over six orders of magnitudes from high vacuum on the low side, to elevated pressure on the high side. In addition, due to thermal considerations, the chamber may have to be of a double-walled, vacuum-jacketed structure. For pressurizing the chamber, the gas handling subsystem can be utilized, provided it is designed for preparing gas mixtures at the appropriate pressure. For chamber venting, the SSF vacuum/vent line can be used. This line provides roughly 10^{-6} bar. One experiment requires

pressure below that provided by the SSF (separate discussion in section 4.8). This experiment will require an experiment-specific capability.

A review of possible high-vacuum pumps was conducted, and a brief summary is provided in Appendix D. Turbomolecular pumps of the type that use magnetic bearings (or those that do not use gravity-fed lubricants) seem most appropriate for the spaceborne applications because of their small size and weight and high throughput. Because of the high rotational frequency of these pumps, there is no vibration or noise. When considering a pump, however, the complete system, including the control and drive electronics, must be considered in terms of the overall power consumption, weight, and size. Another family of pumps that may operate well in the GGSF environment are the getter-type vacuum pumps.

There are some general design considerations appropriate to all high-vacuum systems ($<10^{-6}$ bar); these are briefly discussed in Appendix D[16]. To achieve high-vacuum in a reasonable time, a good conductance path is required between the pump and the chamber. In this case it implies that the pump should be mounted directly onto the chamber and that the chamber diameter at the interface be large enough to create minimum restriction. This latter requirement implies that the high-vacuum chamber should have a geometry compatible with the pump. Therefore, there may have to be a separate chamber for use in the high-vacuum region.

Compatibility between high vacuum and cryogenic temperature. Since the high-vacuum pump directly interfaces with the chamber, it has a large view factor covering the interior of the chamber. The turbomolecular or getter-type pump cannot cool to cryogenic temperatures because they radiate into the chamber. This parasitic radiation heat load may be large enough to preclude efficient cooling of the chamber. Possible approaches to alleviate this issue include the introduction of radiation baffles or an elbow in the flow system. Another solution would be the use of a cryopump (see Appendix D). These pumps operate at a cryogenic temperature and typically are shielded from the chamber. However, for this study it is **assumed** that LN_2 is not allowed on board and this will reduce the effectiveness of a cryopump by an unknown extent at this time and requires further analyses.

Compatibility of low pressure, low temperature, and gas composition. Several experiments require the use of various gas mixtures with low pressure and temperature. In most cases these conditions are intended to form ices of the various substances. Yet all substances, including ices, have a vapor pressure. If an attempt is made to pump the chamber to a pressure lower than the vapor pressure of the substance, the ices would undergo a continuous sublimation and the vapor would be pumped out of the system. Similarly, if the objective is to maintain a gaseous mixture in the chamber, the specified pressure and temperature must be kept above the triple point of the various mixture components. Figure 9 shows the triple point and the vapor pressure of the various gases.

Pressure measurement. Since the chamber may undergo several orders of magnitude in pressure range during the preparation for an experiment, pressure gauging requires special attention. There is no single pressure gauge that covers the complete range from 3 to 10^{-6} or 10^{-10} bar. In the high-pressure range the pressure in the system equalizes over a short time and common diaphragm-type gauges are appropriate. This allows mounting the gauge outside the chamber on

[16] Several excellent references are published by the major manufacturer of vacuum equipment. For instance, (1) Balzers Vacuum Components Handbook and (2) Leybold-Heraeus Vacuum Products, Inc. Product and Vacuum Technology Reference Handbook.

one of the feed or vent lines. For the vacuum, and specifically the high-vacuum range, the pressure gauge is typically also mounted outside the chamber, connected to the feed or vent line. Here, however, the conductance between the chamber and the location of the gauge is very important for obtaining meaningful measurements. It may be a good design practice to make the vent line as large in diameter as possible not only to improve the pressure measurements, but also to cut down the chamber vent time.

GGSF FUNCTIONS SUMMARY

Vacuum standard design practices must be exercised with all chambers design.

Ambiguous requirements between the thermodynamic state of the sample and the experiment environment requirements must be reviewed.

A separate high-vacuum chamber is required to avoid the associated design complexities with the other chambers.

The mounting location of the vacuum gauges and isolation valves must be carefully assessed.

4.1.2.3 Volume Range

The smallest acceptable chamber size requested is 1 cm^3, by experiment 2. This is a collision experiment in which two particles are accelerated toward each other and imaged during their interaction. The experiment is conducted at pressure and temperature ranging from ambient down to lower levels. For the purposes of particle manipulation and acceleration, a small chamber is preferable. A small chamber is also preferable for the purpose of visualization to reduce the required field of view. However, no upper limit is imposed on the size of the chamber.

Large chambers are required by the biological experiments that operate at ambient pressure and temperature. These experiments ideally would operate in a chamber size of the order of 1 m^3. The restriction on the upper chamber size is imposed by the facility (rack) size. A 1 m^3 chamber requires a 1.25-meter diameter (for a sphere) or a 1.1-meter height/radius (for a cylinder); neither geometry would fit into the ISPR rack.

The S&T volume constraints are of two types. The first includes those experiments that specify a minimum chamber size with no upper limit. The second includes those experiments that specify an upper chamber size limit. If no other considerations entered the analyses, these two types of S&T requirements would constitute the requirements for the chamber size. For instance, Figure 5, in section 2.3.1 shows that experiments 6, 8, 13, and 18 specify a lower and upper size limit which can be met by a chamber roughly between 2,000 and 3,000 cm^3. This chamber size does not accommodate, however, experiments 4, 5, 9, 17, etc.

Issue

Upper and lower limits on chamber dimensions and/or volume must be specified, justified, and the impact of deviations clearly stated.

Compatibility between chamber size and vacuum. The pumping time to evacuate the chamber is affected by the overall volume of the chamber, and it is proportional to the chamber volume. At this point, not enough data on the SSF vent line throughput are available to calculate the pumping time. This will ultimately be determined by the conductance of the chamber, vent line, valves, filters, gas scrubbers, etc. There is an advantage in keeping the chamber volume as small as possible for all experiments requiring vacuum.

Compatibility between chamber size and temperature. This issue was discussed earlier from which the conclusion is drawn that the chamber size affects both the minimum temperature one can reach with a given cryocooler size and specific chamber design (i.e., ports, windows and other interfaces), and the time required to reach the operating temperature. There is an advantage, therefore, in minimizing the chamber size for all experiments requiring low temperature.

GGSF FUNCTIONS SUMMARY

Chamber pumping and cooling considerations give preference to small chamber volume. The pumping considerations require high conductance between the chamber and the SSF vent line.

4.1.2.4 Sample Dynamics Considerations and Experiment Duration

Several considerations were discussed so far that favor as small a chamber as possible. Other considerations, discussed next, favor a large chamber for a class of GGSF experiments.

When investigating the physics and chemistry of small particles, all effects under investigation (such as coagulation, agglomeration, etc.) are time dependent. During the time in which these phenomenon take place, the particles are also subjected to other effects that may interfere with the experiment. We are interested in dynamic effects that cause the particles to be lost to the experiment. These effects include motion of the particles in the chamber due to (1) diffusion or Brownian motion (which cause the particles to reach and deposit at the chamber wall), and (2) gravitational sedimentation (which cause the particles to "fall to the bottom" of the chamber). It is the importance of these dynamic effects relative to the effects being investigated which determines whether a meaningful experiment can be conducted in a given chamber size under a given experiment conditions.

The two effects (sedimentation and diffusion) control the particle motion over different operating regimes. These regimes are primarily determined by four parameters: particle size, chamber pressure, chamber size, and the DC component of the residual gravity. The analysis of these effects and that of the competing effects (coagulation, agglomeration, etc.) is fairly complex. A simplified analysis, however, may be useful in highlighting the key parameters and range of these parameters under which diffusion and sedimentation may dominate the experiment execution. We show here some results collected from various references.

Particle sedimentation. Appendix E shows an analysis of ballistic particle motion. The results of the analysis, calculated at 10^{-5}g, are shown in Figure 22. To use the figure, first the characteristic particle time is determined from the top left graph based on the particle size and the chamber pressure. With this characteristic time, the three other graphs are used to determine the particle

settling distance as a function of time, the terminal velocity of the particle, and the stopping distance as a function of the initial velocity. The latter graph is useful for planning the collision experiments (section 4.4.4). This analysis is the way to make the determination as to whether an experiment can be conducted in a given chamber size.

Diffusion. A summary chart showing the distance traveled by a particle due to diffusion as well as due to settling under standard pressure and temperature conditions is shown in Figure 23.[17] Again, this type of analysis is recommended as a basis for the selection of the chamber size.

Particle dynamics summary. Some of the characteristics of particle mechanics are summarized in Table 35, for which a detailed explanation can be found in the cited reference. These characteristics are briefly explained below. The values in the table are different from those plotted in Figure 23 by the value of the Cunningham Slip factor.

The diffusion coefficient, D, an indication of the average kinetic energy of the particle along each coordinate axis (equal to $\frac{1}{2}kT$ based on statistical mechanics) and the particle mobility B. The diffusion coefficient is $D=kTB$, from which value the mean square displacement of a particle over a period t, is $\overline{x^2} = 2Dt$. Here k and T are the Boltzman constant and the absolute temperature.

Table 35. Particle Characteristic[1]

d, μm	D, cm^2-sec^{-1}	G, cm-sec^{-1}	t, sec	ℓ_B, cm	$\overline{\Delta x_B}$ cm	$\overline{\Delta x_s}$ cm
10	2.38×10^{-8}	1.40×10^{-2}	3.08×10^{-4}	4.32×10^{-6}	1.74×10^{-4}	3.02×10^{-1}
1	2.74×10^{-7}	0.44	3.54×10^{-6}	1.53×10^{-6}	5.90×10^{-4}	3.47×10^{-3}
0.1	6.82×10^{-6}	14	8.81×10^{-8}	1.24×10^{-6}	2.95×10^{-3}	8.64×10^{-5}
0.01	5.24×10^{-4}	444	6.76×10^{-9}	3.00×10^{-6}	2.58×10^{-2}	6.63×10^{-6}
Correction factor for nonunity density	ρ^0	$\rho^{-1.2}$	ρ	$\rho^{1.2}$	ρ^0	ρ

[1] Modified from Fuchs, N. A., The Mechanics of Aerosols. Dover Publication, 1964.

The mean velocity, G, is the average particle thermal velocity based on its kinetic energy and is equal to $\overline{G^2} = 3kT/m$. This velocity (and the number of particles per unit volume) determines the number of collisions per unit time.

Relaxation time, t, and Apparent mean free path, ℓ_B, are, to a first approximation, considered the time between collision and the distance traveled between collisions.

The average Brownian Displacement in 1 second in a given direction is given by $\overline{\Delta X_B} = \sqrt{\frac{4Dt}{\pi}}$.

The gravitational displacement in 1 sec at 1-g at STP is given by $\overline{\Delta X_s}$.

[17] Provided by Judith Huntington, SETI Institute.

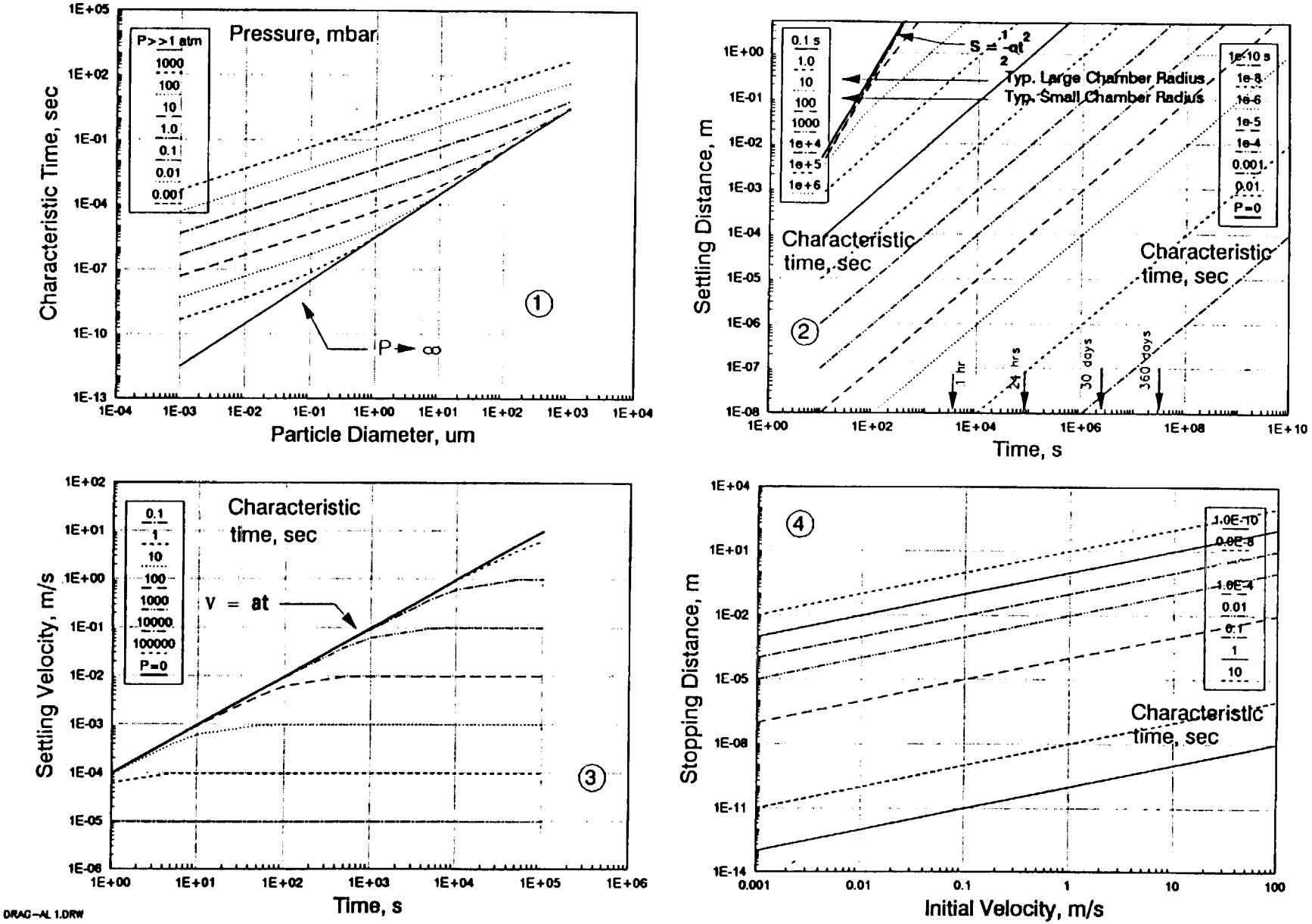


Figure 22. Particle Ballistics at 10^{-5}g (analysis in Appendix E)

Minimum chamber size determination. These characteristic values are extremely helpful in determining the minimum required chamber size. The mean Brownian displacement distance can be calculated from the table for different experiment durations. For instance, based on Figures 4 (section 2.2) and 14 (section 2.7.2), experiment 9 uses particle sizes of 0.01 μm and larger and is expected to last more than a week. For these particles, the mean Brownian displacement distance per second is about 2.58×10^{-2} cm. In 1 week, or 6.048×10^{5} sec, the particles travel about 0.20 meter. Fortunately, the small particles do not survive very long and tend to coagulate and agglomerate rapidly and as their sizes grow their Brownian motion decreases. Otherwise, these experiment conditions can not be met in the GGSF. Repeating this analysis for 1-μm particles, in 1 week they would travel a distance of 0.459 cm.

A similar analysis can be performed for the sedimentation effect. In total vacuum, the particles are in free-fall regardless of their size. For instance, experimenters requiring a low pressure of 10^{-3} - 10^{-6} bar, particles sizes in the range of 0.01 to 0.1 μm, and the experiment duration less than a week (say 1 day). Based on graph 1 in Figure 22, the particle characteristic time is roughly from 0.01 to 0.1 sec. Based on graph 2 in the same figure, the settling distance at 10^{-5}g is for these two sizes roughly from 1 to 10 meters. This indicates the need for caution regarding clarifying any ambiguities in the S&T requirements.

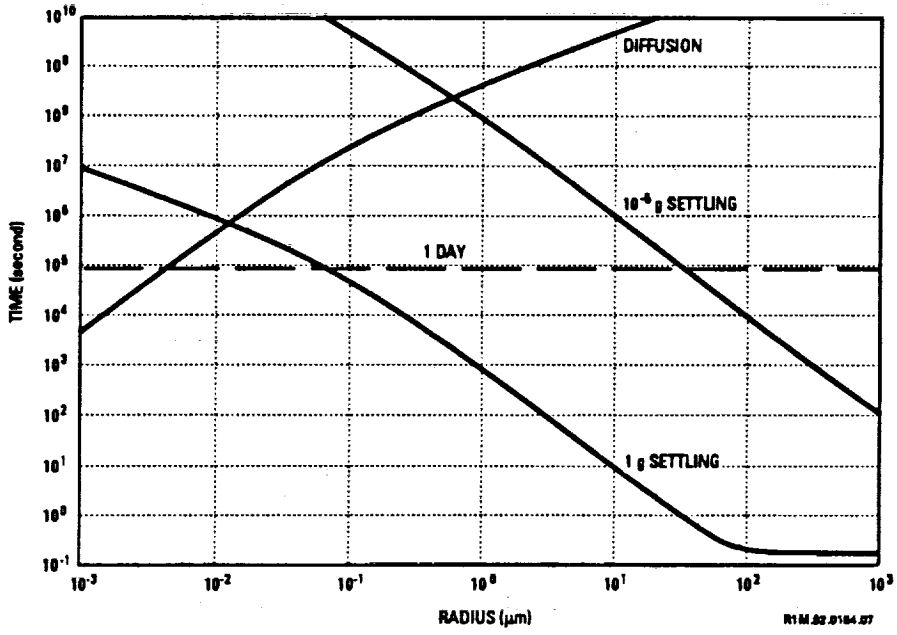


Figure 23. Time Required for a Water Droplet to Move 10 cm in STP due to Settling and Diffusion

GGSF FUNCTIONS SUMMARY

Because of the large number of possible permutations, it is impractical to plot the required chamber size for the various experiments (many particle sizes, pressure range, g-level, etc.). It is important, however, to verify the range of parameters for any proposed experiment and to assess whether sufficient experiment time is available before significant particle loss to the wall either by diffusion or sedimentation occurs.

An accurate assessment of the coagulation, agglomeration, and other effects which may come into play (such as other forces acting on the particles: van der Waals, Coulomb, electrostatic, thermophoretic, kinematic, etc.) as well as sedimentation and diffusion must also be considered. This makes the analysis quite complex, necessitating the use of a reliable computer model.

4.1.2.5 Gas Storage Considerations

The amount of gas storage required for a chamber fill is directly proportional to the chamber volume. Since gases are consumables that require frequent replenishment, a small chamber volume is preferred (see section 4.5).

4.1.2.6 Ports, Windows, Other Openings, and Interfaces

The experiment chamber must provide access to the interior for several S&T requirements. Table 36 summarizes the requirements that were identified as chamber ports or general interfaces.

Table 36. Ports, Windows, and Interface Functional Requirements

ITEM	REQUIREMENT
In-line diagnostics	Particle/cloud characterization, illumination sources, detectors, etc.
Off-line diagnostics	Sample withdrawal for additional analyses
Imaging	Video/photography and illumination
Sample insertion	Various types of samples
Experiment specific	In-chamber devices
Feedthroughs	Separate for electrical power and for data signals
Gas introduction	Fill chamber with desired mixture
Vent	Venting the chamber at the completion of experiments
Measurements	Temperature and pressure transducers
Cleaning	Access for chamber cleaning
High vacuum	High-conductance port for high-vacuum pump

The use of ports on the experiment chamber has a significant impact primarily on the thermal characteristics of the chamber. Windows may allow for radiative heat transfer that increases the thermal load on the cryocooler (or the heaters in the case of the high-temperature experiments).

Other ports and feedthroughs also create a conductive heat transfer path and potential for vacuum leaks. All the ports must penetrate both shells of the chamber (if it is built in two, vacuum-jacketed shells) and, therefore, create a direct conductive path between the outer shell, which is roughly at room temperature, and the inner shell, which is cryocooled (or heated). Thermal considerations suggest the use of insulating sections in such feedthroughs and other techniques to reduce the radiative and conductive heat paths between the two chamber shells. This design area will require special attention since, ultimately, it determines how well (how fast and to what temperature) the chamber can be cooled (or heated) (Appendix B, and section 4.1.2.1).

Optical windows. Windows serve primarily the optical diagnostics and the imaging subsystems. The CCD cameras' windows should have good transmission over the Si response range (i.e., 400 to 1,000 nm). The illumination windows for the imaging subsystem should have a similar range. The diagnostic ports must cover a broader range, roughly from 180 nm to 2.5 μm. This range covers requirements for the scattering experiments. When an FTIR subsystem is installed, the windows should be replaced with the appropriate type of material which transmits over the range of the FTIR measurement spectrum up to 25 μm (i.e., ZnSe).

4.1.2.7 Internal Mounting Provisions

In order to reduce the number of ports and windows, some diagnostics (e.g., detectors) are designated as **in-chamber diagnostics**, and are mounted inside the chamber. Similarly, experiment-specific hardware (e.g., single droplet manipulator, capacitor plates, etc.) may have to be mounted inside the chamber. The chamber should, therefore, provide mounting points for such equipment, as well as interfaces for power and signal output from these elements.

4.1.2.8 Chamber Cleaning Methodology

The chamber cleaning requirements vary from "noncritical" to "sterile." However, all experiments should consider two general issues. The first is the removal of the residues, both solids and gases, from one experiment before conducting the next experiment. The second is the deposition and collection of particles and other condensables on optical windows and their impact on the measurements.

Residue removal. Gases can be removed by venting the chamber via the SSF vacuum line, down to 10^{-6} bar. This seems to be sufficient but in some cases it may not be. If the next experiment requires, say, a pressure of 10^{-4} bar with an accurate mixture including 1% of a gas A, then the partial pressure of gas A is 10^{-6} bar. This partial pressure is as high as that of the mixture left in the chamber after venting the previous experiment.

Particle removal from the chamber may be relatively easy when the pressure in the chamber is near atmospheric. In that case the particles would flow with the vented gas. At the low vacuum, however, the opening of the vent line does not induce a flow -- in the continuum sense -- of gas which can carry the remaining particles out. The removal of the particles may not be a trivial task.

GGSF FUNCTIONS SUMMARY

The specification of mixture composition for the experiments with partial pressures of gases below ~10^{-5} to 10^{-6} bar may be meaningless, and should be discouraged unless special vacuum pumping is utilized. Similarly, for vacuum experiments, the control of the initial mixture composition should consider about 10^{-6} bar of residue gas in the chamber.

The removal of particles from the chamber after low-pressure experiments may require refilling the chamber with a gas, e.g., GN_2, before venting.

The second problem mentioned above is that of particle and condensable deposition on optical surfaces (windows). Once a layer of particles is deposited, it may affect the measurements conducted through a window. For instance, transmission or extinction measurements may be misleading. Some of this effect may be taken out by recalibration (or null setting) for such measurements. But in general, removal of the particles is desirable since they may interfere with the new experiment. Since the nature of those deposits is not clear at this time, it is hard to prescribe a universal technique for the removal of the particles off optical surfaces.

Several approaches have been identified for the chamber cleaning function. The techniques are listed below in order ranging from the simplest to the most complex.

- Treat windows with antistatic coatings
- Evacuate chamber, vent particles, and boil-off any condensable liquids
- Purge with GN_2 and evacuation cycles
- Bake-out and vent for materials with a low vapor pressure (requires installing low-temperature heaters in the chamber)
- Schedule experiment sequence to reduce the impact of contamination (experiments requiring cleaner chambers are performed first, followed by those experiments in which cleaning is less critical)
- Remove and replace the chamber with a new chamber
- Use the glove-box and workbench on SSF to open, clean, and reassemble the chamber
- Return chamber to Earth for cleanup and reassembly.

The cleanup of the chamber on board the SSF is not desirable, and may be in conflict with the requirement to build a chamber that can retain a high vacuum. First, seal integrity of the vacuum system cannot be guaranteed, and second, for high vacuum, seals cannot be reused and must be replaced and tightened to a carefully specified torque; operations that may be difficult to perform reliably under the SSF conditions.

Another reason to discourage opening the chamber on board is the hazard of cabin contamination from trapped particles.

Thus, although the chamber should be designed for relative ease in maintenance, including cleaning and insertion/removal of experiment-specific in-chamber hardware, performing this function on board is undesirable.

4.1.3 Implementation Approach

Based on the broad range of pressures, temperatures, and other chamber interface requirements discussed in the above subsections, and on the basis of the sample generation requirements and

their impact on the chamber interfaces (discussed in section 4.2), the chamber functional requirements are defined in the summary below. Figures 5, 6, and 7 in section 2 show how the various experiment requirements of pressure, temperature and volume are matched by the chambers selection.

GGSF FUNCTIONS SUMMARY

Because of conflicting design requirements, four different chambers are defined to meet the requirements of all the experiments: a large-volume chamber, a low-temperature chamber, a high-temperature chamber, and a high-vacuum chamber.

The chambers should have identical mechanical and electrical interfaces so that all diagnostics would be completely interchangeable with all the chambers. All sample generators shall be totally interchangeable with all chambers. All chambers should have these interfaces in "equivalent" positions so that the GGSF could function identically regardless of which chamber is attached.

The large-volume chamber shall provide at least one order of magnitude larger volume than the low-temperature chamber (e.g., >50,000 cm^3) and operate over the pressure and temperature range from 1 to 10^{-6} bar and from 200 to 400 K, respectively. The low-temperature chamber shall provide about 4200 cm^3 and operate over the pressure and temperature range from 3 to 10^{-6} bar and from 60 to 400 K, respectively.

The high-temperature chamber shall operate up to 1200 K and over the pressure range from 1 to 10^{-6} bar. The high-vacuum chamber shall operate down to 60 K and pressure down to 10^{-10} bar.

Chamber sterilization is to be performed on Earth prior to installation on board GGSF.

A fifth chamber which has no active temperature control, may be useful for a range of many of the experiments and should be considered for the initial flight configuration.

4.2 Sample Generation

4.2.1 Summary of S&T Requirements

A summary of the sample generation range requirements is given in Table 37.

4.2.2 General Considerations

This section discuses various approaches and issues for the generation of samples, including the dispersion of solid particle clouds, aerosol generation, and other techniques. Topics covered in this section include the diversity, effects of electrical charges, carrier gas considerations, and modularity-related issues.

The **diversity** of the requirements in terms of the types of samples, materials, sizes, and quantities presents a major challenge. On one hand it would not be useful to develop a custom sample generation technique for each of the experiments. On the other hand, many of the known

commercial techniques for generating aerosols or dispersing particles have relatively limited range of parameters which may not be universally applicable. Commercial instruments that cover a limited range of the requirements do exist, but often implicitly rely on gravity for their operation, so even simple instruments may have to be modified for operations in μ-g. For instance, the vibrating orifice aerosol generator (VOAG), a well-proven technique, uses gravity to collect the excess fluid into a return line. When it comes to single particles/droplets there are no commercial instruments. Essentially, the same can be said about soot and smoke generators. Such instruments, found in various labs, are often "home-made," and have a fairly narrow range of applicability. Condensation generators, often known as cloud-chambers, usually operate near saturation to avoid the need for cooling the chamber to cryogenic temperatures. No commercial "cloud chamber" is available for high-temperature gases (metals) or low-temperature gases (CH_4, NH_3, etc.). *Hence, the challenge is to identify techniques that will minimize the number and type of sample generators required to fulfill the majority of the experiments.*

Table 37. Summary of Sample Generation Requirements

Sample Type	Exp. No.	Materials	Size (μm)	Concentration (No./cc)	Pressure (bar)
Solid particles	1, 3, 5, 8, 13, 15, 17, 18	Silicate grain, salt, quartz, basalt, carbon, olivine, pyroxene, alumina, TiO_2, MgO, microspheres	0.01 - 1000	1 - 10^8	10^{-10} - 1 (10)
Liquid aerosols	11, 18, 19, 20	Organic solutions, microbes in nutrient solution, others TBD	0.1 - 50	300 - 10^5	0.05 - 1 (11)
Single particle/ drop	1, 2, 4, 12	Silicates and ice-coated silicates, tholin, ices of NH_3, CO_2,	1 - 10^4	One or two only	10^{-6} - 1
Soot and smoke	3, 6, 13, 17, 21	Hydrocarbon combustion soot, MgO, PAH	0.0005 - 10	1 - 10^8	10^{-10} - 1
In situ samples	9, 13, 14	From gas mixtures using RF, UV, E-discharge, E-fields	0.005 - 10	10^5 - 10^8	0 - 1
Low-temperature condensation and nucleation	1, 2, 3, 6, 7, 8, 16	Ices of H_2O, CO_2, CH_4, NH_3	0.01 - 2,000	1 - 10^8	10^{-6} - 1
High-temperature condensation	10, 15, 16	Bimetallic elements, metal-bearing gases, metals, silicates	0.01 - 100	10^6- 10^{11}	10^{-6} - 1

One common problem shared by all small particulates (solid and liquids) is related to **electrostatic charge** accumulation. Due to a number of reasons such particles are charged and tend to stick to surfaces or to other particles. No function to neutralize the particles was identified in the workshop questionnaire. Since small particles appear charged in their natural environment, the charge and the ensuing forces may be a part of the science investigation. However, particle accumulation on windows, or other dielectric surfaces, may interfere with the accuracy of measurements and ultimately block the chamber optical access. In addition, the motion of the charged particles in the chamber may be affected by the presence of walls and windows, biasing the experiment results.

Charge removal, or **neutralization**, is often done in the laboratory by passing the particles, carried by a stream of carrier gas, through a vessel containing Kr-85 (a radioactive isotope) [18].

The flow does not actually come into contact with the Kr-85 since it is contained in a shielded vessel, but a sufficient amount of gamma radiation is emitted into the flow path to neutralize the charges. Neutralization could, in principle, be applied in the GGSF, but it could raise critical safety issues and may require added shielding. Another method for charge neutralization is by means of a corona discharge, but the potential problems here are no less than with the Kr-85 method.

Another issue is related to the sample introduction into the chamber. Both aerosol generators and particle dispersion systems often use a pressurized **carrier gas** for the introduction of the fine particles into the desired location. The pressurized gas also is the source of energy which is required to break up (atomize) the liquid in a nebulizer, or disperse and break up the particles in a deagglomerator[19,20]. This approach may create a special problem in some of the GGSF experiments. Since the chamber often must be filled with a mixture of gases of a fairly accurate composition (section 2.4.3), pressure, and temperature, the introduction of the sample by means of a different carrier gas may be unacceptable. Using the same mixture as that in the chamber for the carrier gas would still affect the chamber pressure and temperature. And finally, those experiments which require vacuum in the chamber would be unable to tolerate the introduction of a carrier gas with the experiment sample. Thus, there is a need (at least for a class of experiments) to identify sample generation techniques that do not use, or minimize the use of, carrier gas. If this is not possible, the impact of the addition of a carrier gas on the experiment initial conditions must be assessed.

From the requirements and the discussion so far, it seems clear that no single sample generator can meet all the requirements. There is a need for several devices, and these devices must interface with any of the experiment chambers via a common interface. The approach suggested is that of **modularity and commonality**. The different sample generators will have common mechanical, electrical, and control interfaces and should have a relatively simple removal and installation technique. This approach allows for future growth and for the installation of new generators which become necessary for future new experiments.

In the remainder of this section, we review some of the commercial technology for sample generators and develop the rationale for the functional facility requirements in this area. The literature covering these technologies can be found in the references. [21,22,23,24,25]

A few general sample generation methods are summarized in Table 38; these and others are discussed in the following subsections.

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[18] TSI Aerosol Neutralizer, Models 3012, 3054, 3077.

[19] Fine Particles: Aerosol Generation, Sampling, and Analysis. Edited by Benjamin Y.H. Liu. Academic Press, 1976.

[20] Operation and Maintenance Manual for the Shapples Corporation Micromerograph.

[21] H.L. Green, and W.R. Lane. Particle Cloud: Dust, Smoke, and Mist. E.&F.N. Spon, London, 1964.

[22] R. Cliff, J.R. Grace, and M.E. Webber. Bubbles, Drops, and Particles. Academic Press, 1978.

[23] C. Orr, Jr. Particulate Technology. McMillan Co, 1966.

[24] S.K. Friedlander. Smoke, Dust, and Haze: Fundamental of Aerosol Behavior. Wiley, 1977.

[25] R.R. Irani, and C.F. Callis. Particle Size: Measurement, Interpretation, and Application. Wiley, 1963.

Table 38. Sample Generation Techniques

LIQUID AEROSOLS: CONTINUOUS FLOW	NONSOLUBLE SOLIDS:
Vibrating orifice aerosol generator	Form aerosols of suspension of the solids in a liquid carrier (hydrosol), then evaporate carrier.
Spinning disk	
Nebulizers	
Electrostatic generator	
Ultrasonic generator	
LIQUID AEROSOLS: BATCH /ON-DEMAND	DRY POWDERS
Thermal jet ejector	Fluidized bed
Squirt gun; atomizers	Aspiration feeder
"Spray-can"	Auger feeder
SOLID PARTICLES	Blast disperser
SOLUBLE SOLIDS:	Arc evaporator
Form aerosols of the solution and evaporate solvent	Exploding wire

The total amount of sample required for the dispersion is a useful quantity for sizing the sample generator. The sample total weight is $m = \rho\frac{\pi}{6}d^3 \cdot C \cdot V_{exp} \approx d^3 \cdot C \cdot V_{exp}$, where the terms in the equation stand for the particle density, diameter, concentration, and experiment chamber volume, respectively. As an example, for 1-μm particle dispersed in a 4,200-cc chamber at 1,000 particles per cc, m=4x10^{-6} gm. A review of other experiment conditions indicates that in most cases the amount of sample to be dispersed is in the subgram level.

GGSF FUNCTIONS SUMMARY

No charge neutralization function is indicated by the S&T requirements.

All sample generators should be interchangeable and designed with common interfaces.

During MTC, sample generators will have to allow for repeated tests with similar or different sample materials, with no operator intervention. Each type of sample generator is to be designed for repeated and automated operations, implying that the sample materials may have to be contained within the generator as appropriate.

Sample generation methods that do not introduce a carrier gas are needed for the vacuum, and other experiments.

Issue

The accurate measurement of the amount of sample material to be introduced into the disperser requires careful consideration.

4.2.3 Solid Particle Dispersion

A review of commercial and laboratory systems reveals that most methods (a) rely on gravity, (b) do very little to assure deagglomeration, (c) use a carrier gas, or if (a), (b), or (c) do not apply, then (d) these systems operate with very large particles (e.g., millimeter size).

A second issue to consider is the source for dry particles of submicron size, what the size distribution is, and how these particles should be handled to avoid the collection of moisture since small particles often are hygroscopic (discussion of sample pre-test storage in section 4.6).

A third issue is the loading of the particles into the sample disperser, and how repeat experiments are handled.

Once an appropriate method is identified, it should be characterized over a range of operating parameters such as dispersion pressure, particle size, particle size distribution, particle composition or material, total particle mass to be dispersed, etc.

GGSF FUNCTIONS SUMMARY

Solid particle dispersion is to operate with particle sizes over five orders of magnitude, generate concentrations range over eight orders of magnitude, and use a variety of materials; no commercial or laboratory technique can presently meet this order.

Many experiments require no carrier gas.

During MTC automated sample measuring and loading is needed. The actual amounts of sample are often in the μ-gram to milligram range.

4.2.4 Liquid Aerosol Generation

The generation of liquid aerosols under the GGSF requirements is somewhat simpler than the generation of solid clouds. There are many commercial systems ranging from liquid atomizers used for automotive fuel injection and diesel injectors, to fire suppression nozzles, nebulizers, etc. Some techniques do use a carrier gas, others do not. Some techniques rely on gravity to feed the liquid or to return the excess liquid. These issues can generally be overcome by the use of pressurized feed system, etc. Various μ-g liquid aerosol generation techniques were tested for the ACPL[26] program, although the requirements were quite different from those in the GGSF (e.g., the size range was considerably smaller and the aerosol monodispersity and repeatability requirements were very stringent). Additional data can be found in other documents.[27]

For liquid droplets, the issues of loading the sample into the generator and handling repeat experiments are also more manageable than for solid particles.

[26] U. Katz. Study to Perform Preliminary Experiments to Evaluate Particle Generation and Characterization Techniques for Zero-Gravity Cloud Physics Experiments. NASA CR-3486, 1982.

[27] L.R. Eaton, and S.L. Neste. The Phoretic Motion Experiment (PME) Definition Phase. Final Report prepared for NASA/MSFC under contract NAS8-34319, 1982.

GGSF FUNCTIONS SUMMARY

Aerosols are to be generated ranging in size over several orders of magnitude.

No S&T requirements regarding the monodispersity of the aerosols are specified.

4.2.5 Single Particle/Droplet

Relatively large particles can be manipulated mechanically. Such particles can be released into the chamber by inertial techniques because their momentum is high relative to the forces holding them to the mechanical manipulator. This technique was successfully used by TRW for the Droplet Combustion Experiment, a NASA μ-g program, in which a single millimeter-size droplet was formed on a tip of a syringe, and then released using inertial positioning.

For the small particles/droplets this may not be true. The forces holding them to a mechanical manipulator are related to either surface energy (surface tension) and wetting properties of both the particle and the manipulator, or to electrostatic forces. The subject of particle adhesion is not well understood and is barely covered in the literature.[28,29]

With very small particles, difficulties may also be related to observing the particle and manipulation. The introduction/injection of a single particle/droplet is also discussed in section 4.4.4. in relation to the collision experiments.

4.2.6 Soot and Smokes

Soots are readily formed during the combustion of hydrocarbon fuels under fuel-rich conditions. In laboratory experiments, the flow containing the soot is passed through the experiment chamber whose volume is flushed several times with the carrier gas/sample mix in a continuous flow process. Two approaches can be visualized for the GGSF. In the first, a continuous flow diffusion flame is established and the soot generated in the flame is carried together with the other reactants and products into the experiment chamber. In the second technique, a closed volume is used for the combustion of a fuel-rich mixture. In fact, only a small amount of oxygen is needed to raise the combustion chamber temperature to a point at which the hydrocarbon fuel pyrolyses and soot is formed. The combustion chamber is then opened into the experiment chamber and the flow is established to transfer the soot into the experiment chamber.

The former technique is a continuous flow type, and it relies on a relatively high flow of carrier gas. The latter technique is a batch process but it operates in a combustion chamber that may reach high pressure. Both techniques require an ignition source. Safety issues related to the ignition, as well as to the general flow of a combustible mixture and a fuel, and potential leaks are to be considered. An alternative to these techniques is to bring soot from Earth. However, soot suffers from "aging" proprieties and therefore this technique may not be acceptable to the experimenters. It is unclear also whether it is possible to disperse such soot effectively, since soot particles are typically of the submicron size.

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[28] A.D. Zimon. Adhesion of Dust and Powder. Second Edition, Translated from Russian and published by the Consultants Bureau, New York, a Division of Plenum, 1982.

[29] Mittal, K.L. (Editor). Particles on Surfaces 2. Detection, Adhesion, and removal. Proceedings of a Symposium on Particles on Surfaces, Held in conjunction with the 19th annual meeting of the Fine Particle Society, (1988, Santa Clara, Calif.). Plenum Press, 1989.

The final issue is related to the control of the soot size and concentration. It is not possible to control these parameters very well. The soot is formed in the combustion process and immediately begins to undergo morphological changes and agglomeration, etc. Thus the number density of the soot particles and their size is whatever is produced by the process.

GGSF FUNCTIONS SUMMARY

A combustion chamber design is required for the generation of soot from hydrocarbon fuels.

Other "smokes" are also formed in a combustion process by burning different fuels, e.g., MgO.

4.2.7 *In situ* Generation

The *in situ* sample generation techniques which were proposed include UV, RF, and electrical discharge. These methods are simple to implement.

The **UV source** could be a deuterium lamp, a mercury lamp, or another kind of line spectrum or continuum emitter, depending on the specific wavelength required. In general the source can be isolated from the chamber environment via a UV transmitting window. (See Section 4.1.2.6. Ports, Windows, and Other Openings.) It is desirable to expose as much as possible of the experiment volume to the UV radiation in order to ensure a homogeneous photolytic reaction throughout the volume. For that purpose the UV radiation should not be collimated and the source should be positioned as close as possible to the sample generation port interface.

Design and safety issues are to be considered with the UV source. First is the electrical power and lamp cooling requirements. The electrical power to the lamp may cause heating of the housing and create a large radiative load on the cooled chamber, such that forced convection cooling of the UV source may be necessary. Secondly, for radiation in the range below 200 nm, the interaction with the cabin O_2 will create ozone which then partially absorbs or blocks further UV radiation. The convective flow for the lamp cooling can be used to disperse the ozone. To minimize this effect, however, the optical path between the lamp and the window should be as short as possible, and recirculated with GN_2 if possible. The formation of ozone may become a safety hazard (it is an eye and throat irritant).

The **RF source** could be a coil placed in the experiment chamber. Similarly the **electrical discharge** system could be positioned inside the experiment chamber. Both systems could utilize the common sample generation interface.

GGSF FUNCTIONS SUMMARY

The in situ generators are to match the common sample generator interfaces in the experiment chamber.

Better definitions are needed for the UV source (spectral range and radiance level), the RF source (frequency and power), and for the electrical discharge characteristics.

4.2.8 Low-Temperature Condensation

These experiments form ices from vapors by cooling the chamber to below the saturation point of the gas mixture. Homogeneous condensation is achieved by supercooling, or heterogeneous condensation is achieved on condensation nuclei that are introduced into the chamber. No major problems are expected here. However, since the chamber cooling is achieved by cooling the wall and the gas mix then cools by conduction, a significant condensation is expected on the chamber wall. This effect should be analyzed and considered in the experiment design.

4.2.9 High-Temperature Vapor Generation

Condensation is achieved by cooling vapors to below the saturation temperature. The difference between the experiment conditions in this section and in the previous one, is that the vapors are of high-temperature materials such as metals and silicates. The vapors are formed in a furnace- type sample generator that is attached to the chamber at the sample generator port. Since the furnace operates at high temperature and the chamber may be cooled to a low temperature, adequate thermal (conductive and radiative) isolation is essential.

4.3 Diagnostics

4.3.1 Summary of S&T Requirements

The GGSF diagnostics requirements are divided into categories as shown in Figure 24. The S&T requirements for the environmental diagnostics relate to pressure, temperature, gas composition, and g-level and are discussed in sections 2.4.1, 2.4.2, 2.4.3, and 2.6.6, respectively. The sample characterization diagnostics are further subdivided into off-line (sections 2.6.3 and 2.6.4) and in-line techniques. This latter group is further subdivided into optical scattering methods and imaging (sections 2.6.1 and 2.6.2, respectively).

The range of parameters covered by the diagnostics includes:

- Pressure from 10^{-10} to 3 bars
- Temperature from 10 (4 desired) to 1200 K
- Gas composition quantification for all mixtures
- G-level from 10^{-6} (DC) to about 10^{-2}g at 50 Hz (or the specific expected SSF spectrum)
- Sample particle size characterization from 0.01 to 10,000 μm
- Particle concentration from single particle to 10^{8} particles/cm^3
- Optical characteristics of samples
- Imaging and photography
- experiment-specific measurements.

4.3.2 Environmental Diagnostics

Pressure. The applicable types of pressure transducers for use at the different pressure regimes are shown in Figure 25. Since a particular chamber will support a number of experiments operating over a wide range of pressures, each chamber must be equipped with the appropriate suite of pressure transducers to cover the complete range. **Fast response time** is not required since no experiment is dealing with events which will alter the pressure rapidly. For this reason, the transducers can be physically mounted remotely from the chamber with a tubing connecting the chamber to the transducer. This will also allow the use of valves to **isolate the transducer** from the chamber when necessary. For instance, when high pressure is used, the vacuum gauge may

be damaged unless it is isolated. In some cases, it may be desirable to isolate the gauge to prevent contamination by particles, liquids, and other materials in the chamber.

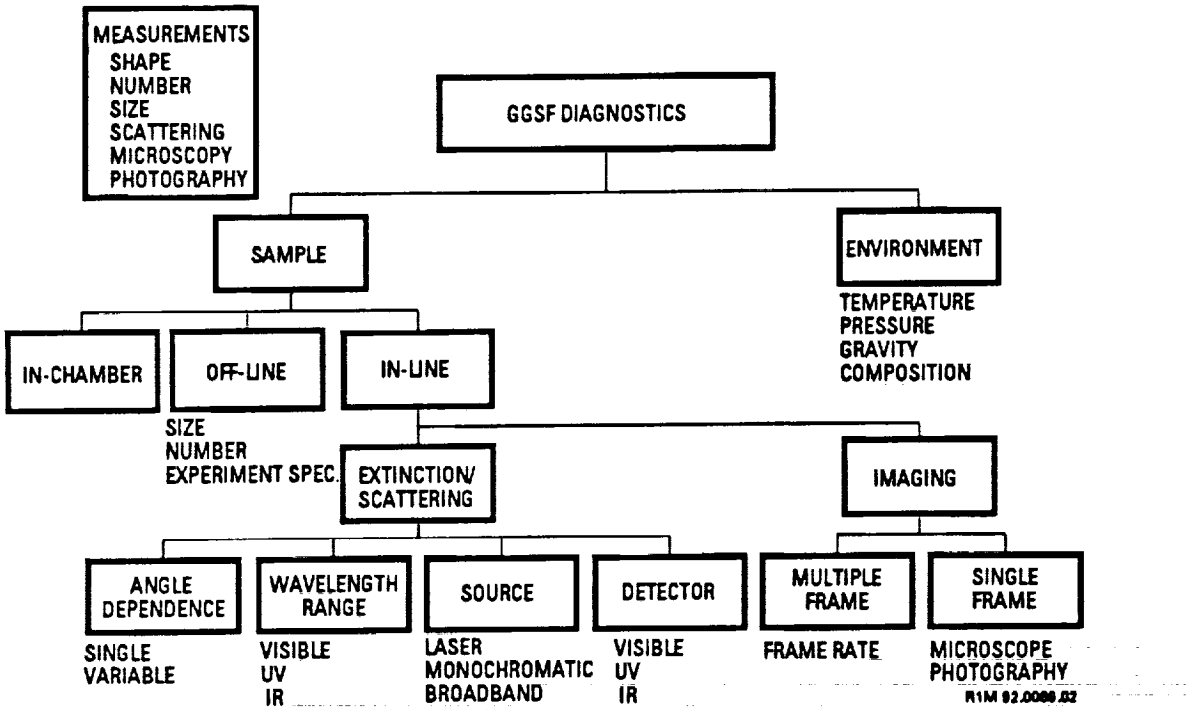

Figure 24. Diagnostics Functions Required for the GGSF

The vacuum gauges should be **insensitive to the composition** of the atmosphere since this would complicate calibration. For instance, the common Pirani gauge, or other gages which measure the thermal conductivity[30,31] of the gas, do not meet this criteria. The various ionization-type gauges may be more suitable although this issue will persist to some degree with all methods due to the wide range of mixtures and gases of interest.

Vacuum and pressure gauges are also required for the **mixing chamber** and similar considerations should apply in that case. These gauges will be used to measure the partial pressure of the gases, so relatively good accuracy and precision are needed.

GGSF FUNCTIONS SUMMARY

Vacuum and pressure gauges are required for the mixing and experiment chambers.

High conductance is required between the chambers and the vacuum gauges.

Isolation valves are necessary to prevent damage to the vacuum gauges from contaminants and during operations outside the range of the specific gauge.

[30] J. P. Holman, Experimental Methods for Engineers. McGraw Hill, 1971.

[31] E.D. Doebelin Measurements Systems: Application and Design. McGraw Hill, 1975.

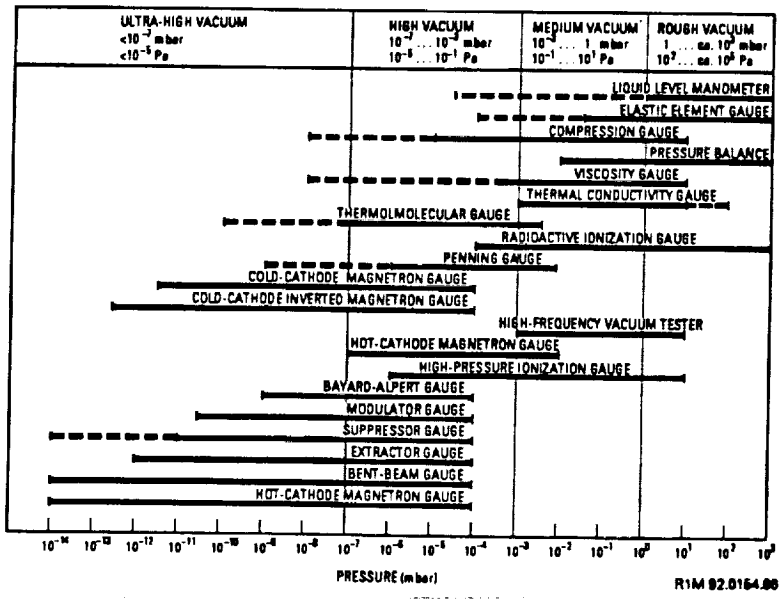

Figure 25. Vacuum Gages Required for Low Pressure (dashed lines indicate a possible extension of the range of operations)

Chamber temperature. The experiment temperature must be measured. The chamber wall, the gas, and the particles may all be at different temperatures. Further, the wall temperature may not always be uniform. As discussed earlier the chamber is attached to a cooler at one location and heat is removed via conduction. Therefore, a temperature gradient exists for as long as there is heat removal by the cryopump. Further, parasitic heat leakage adjacent to fittings and flanges and radiative heat leakage through windows contribute to the local temperature gradients in the chamber structure. In addition, gas temperature may also be nonuniform because the gas is cooled by conduction (in the absence of natural convection). This subject will require a substantial design and optimization effort and the difficulty should be carefully considered by the experimenters when specifying the S&T requirements.

When steady-state conditions are reached, the gas may be at a fairly uniform temperature, but probably never at a total uniform temperature. This should also be considered by the experimenters when specifying S&T requirements. Further, at very low pressure the gas temperature begins to lose its meaning, and only the wall temperature can be measured and reported. In general, the chamber temperature may be easily measured by placing the appropriate number of sensors (e.g., RTDs, thermistors, TCs). To measure the gas temperature a sensor must intrude into the gas volume. The effect of this intrusion on the experiment must be assessed by the investigators, some of whom may choose to withdraw the sensor. The sensor should be fairly well insulated from the wall through which it intrudes into the chamber since heat conducting along the sensor's electrical conductors may dominate over the local gas-solid thermal impedance, in which case the sensor would provide the wrong reading.

The option of optically measuring the temperature using a pyrometer or radiometer has also been reviewed. These instruments are often used for the measurement of temperature at a higher range than expected with GGSF. The literature contains volumes of references on the subject but only

one is cited here, describing some related work done by the author's organization.[32] Since the GGSF is dealing with a low-temperature range, there is no good reason to attempt to use optical pyrometry/radiometry. In fact, the difficulties may outweigh the benefits and simple intrusive devices may provide the required accuracy at a greatly simplified hardware solution. For instance, at 200 K, the peak of the Planks blackbody curve is at 15 μm. This implies that the radiometer will have to use detectors tuned to these very long wavelengths (LWIR). And, although various Si:X (doped) sensor are available, they themselves have to be cooled to LN_2 or even LHe temperature in order to achieve the required quantum efficiency. The sensors will have to be housed within a cold shield to avoid "seeing" anything which is at room temperature (which may be impossible if one has to look through an uncooled or partially cooled chamber window) since the radiation noise level will basically overwhelm the signal. This is a complication that is not warranted in light of the relatively benign technology for contact temperature sensors.

The response time of the temperature sensors is also not critical. A sensor characteristic time of several seconds seems acceptable.

Gas composition and humidity. Measuring the gas composition and humidity is not an explicit S&T requirement, but it is a **derived** requirement in order to control these quantities to the specified accuracies. Typically a gas chromatograph (GC), a mass spectrometer (MS), or a combination GC/MS is used for this purpose. When the gases in the system are known in advance and the question is only their relative amounts, a GC is a simpler tool for the job. An MS would be used to identify unknown substances and is probably not needed in the GGSF. The GC is composed of a sampling valve (with a drive for the valve), a separation column, and a detector. In addition it requires a carrier gas, typically He. Commercial components or custom-developed miniaturized systems may be utilized for the GGSF. The miniaturized GCs, developed at NASA/ARC and built by TRW over the years for the various planetary missions, would be effective. Design questions such as the specific selection of the column packing, whether a programmed temperature control is needed, or if two columns may be used to avoid heating a single column, can be assessed in the future in more detail. The GC will require interface to the vent line both during the sampling loop fill and to vent gases passing through the detector.

Several types of **humidity** sensors are available, yet it is not an easy measurement to perform. The humidity is measured in the mixing chamber in which the gas mixtures are prepared. The moisture, or water, is added to the mixture, and the relative humidity is then verified before using the mixture in the experiment. For most experiments there is no requirement identified for monitoring the relative humidity in the experiment chamber, although this can be done off-line by drawing a sample into the GC.

4.3.3 G-Level

Knowledge of the acceleration forces in three axes within the experiment chamber is required during experiment operations. Because of the dynamic coupling between the chamber and the surrounding structures, it may be important to attach the sensor head to the chamber, rather than to the GGSF rack. The accelerometer should be capable of monitoring the DC component down to a level of 10^{-6} g, preferably in three axes. The AC component must also be monitored. The specific required range of frequencies and amplitudes can be stated once the SSF environment is

[32] Gat, N., Cohen, L.M., and Witte, A.B. Three Color Pyrometer for the Burning Particle Temperature Measurement. Presented at the JANNAF Combustion Meeting, Monterey, CA. Oct. 1983.

better defined. The Space Acceleration Measurement System, SAMS[33], an accelerometer package developed by NASA/LeRC for the purpose of monitoring the g-level during STS experiments, should satisfy the GGSF requirements.

SAMS consists of a main electronic unit which can monitor up to 3 triaxial sensor heads. The unit is flight qualified, and capable of measuring 10^{-6}g. Other specifications are given in Table 39.

Table 39: SAMS Specifications

PARAMETER	MAIN UNIT	SENSOR HEAD
Weight, kg	34	1.25
Volume, cm^3	59,465	1,230
Power, watt	65	-
Cable length, meter	< 7	-

GGSF FUNCTIONS SUMMARY

- *Chamber pressure for the full range from low vacuum to several bars is to be measured with slow response-time gauges that are insensitive to the composition.*
- *Chamber wall and gas temperatures are to be measured each at two to three locations, with slow-response sensors. No radiometers for very-low-temperature measurements are recommended.*
- *A GC will be used to quantify, verify, and monitor the composition of the experiment gas mixture.*
- *A humidity sensor will monitor the moisture level during the preparation of mixtures in the mixing chamber. The GC may be used to measure the moisture contents in a gas sample withdrawn from the experiment chamber.*
- *A three-axes accelerometer capable of monitoring the DC component down to 10^{-6}g in the chamber is to be used.*
- *The need for a chamber vibration isolation has to be assessed through a detailed analysis.*

4.3.4 In-Line Diagnostics

In-line diagnostics is a category of **sample characterization** methods that do not require sample removal. Various optical techniques can be used to estimate particle (or droplet) size, distribution, concentration, and other optical properties such as index of refraction, etc. A good summary of the various techniques can be found in several references.[34,35] The approach for quantifying particle parameters based on their optical properties ranges from extinction measurements, based on the Beer-Lambert law, to Rayleigh scattering for particle sizes smaller than the wavelength of light ($d << \lambda$), or the detailed Mie scattering theory in the range $d \approx \lambda$.

[33] SAMS, Published by the NASA Office of Space Science and Applications, Microgravity Science and Application Division, and the NASA LeRC Space Flight Systems Directorate.

[34] Optical Engineering, Special Edition on Particle Measurements, Vol. 23, No. 5, September/October 1984.

[35] R.D. Cadle. The Measurement of Airborne Particles. Wiley InterScience, 1975.

The scattering pattern of particles depends on their size relative to the wavelength of radiation, their shape, and their complex index of refraction.

In general (for simplicity), to allow the calculation of the scattering pattern by either a single particle or multiple scattering by a cloud of particles, the theories assume that the particles are spherical and their complex index of refraction is known. The analyses become much more complex when the particles are nonspherical, or when multiple scattering must be considered. In the GGSF, scattering measurements can be performed from which the particle information is inferred, usually by a deconvolution of the measurement data. The more data are collected, the more accurate becomes the mathematical deconvolution, since most often the particles are nonspherical and/or their index of refraction is unknown.

The possible types of measurements include **nephelometry or turbidity**, in which the light (typically, but not exclusively, white or multispectral) attenuation (and scattering) through the cloud is measured; **angular scattering** measurements, which provide information on the angular pattern of scattering; **spectral scattering,** which provides additional information on the particles since their index of refraction (both the real and imaginary parts) are often a function of the wavelength. In **diffraction** measurements a collimated monochromatic light, diffracted by the particles, is collected through a Fourier Transform lens to form an interference pattern. The undiffracted, light is focused to a point whereas the diffracted light creates an interference pattern with concentric rings of various intensities.[36] The radii and intensity of these rings are directly related to the size and number density of the particles. The theory assumes single scattering, and it becomes very complex if multiple scattering must be considered. This technique can be used either in a forward or backward mode.

All of the above measurements provide some degree of *ensemble average* particle characterization. The analytical tools required to interpret the data vary in complexity based on the assumptions and on what is known about the particles. Empirical techniques may be used to simplify the data interpretation process. Calibration done with the actual particles is most often the simplest approach.

In general, for all the optical techniques, there exists a convenient range of operations in which the effect is easily measurable. For instance, for extinction measurements (the total of scattering and absorption) using Beèr-Lambert law, the relationship between the light entering and leaving the test chamber is given by $\frac{I}{I_0} = \exp(-Qnd^2L)$, where the terms in the exponent are

extinction efficiency, number density, particle diameter squared, and optical path length, respectively. In general, extinction between, say, ~10 to ~75% is a convenient region to operate. (Too low extinction does not provide sufficient measuring sensitivity, while too much extinction does not provide sufficient signal level.) Hence, based on a chamber size, the range of particle number density, and diameter which meets such criteria can be determined.

Rearranging the equation above to express the relationship between the particle size and the number density, one obtains: $n \approx \frac{1}{L}\ln(\frac{I_0}{I}) \cdot \frac{1}{d^2}$ for particle diameters comparable to or greater than the wavelength. For a given particle size, however, the required change in number density which will change the beam extinction from, say, 1 to 99% is, therefore, only

[36] J. Swithenbank, *et al.* A Laser Diagnostic Technique for the Measurement of Droplet and Particle Size Distribution. AIAA paper no 76-69. AIAA 14 Aerospace Sciences Meeting, Washington, DC. Jan 1976.

$\ln(0.01)/\ln(0.99) \cong 460$, or less than three orders of magnitude. If we limit ourselves to a beam extinction in the range of 5 to 95% the corresponding number density change is only a factor of ~60, or not even two orders of magnitude. A review of section 2.5 reveals, however, that some experiments attempt to cover a much broader range of particle densities. Clearly these experiments will require more than one technique.

The range of operations for all types of in-line techniques is shown in Figure 8 between the two lines superimposed over the distribution function. The figure notes also the off-line techniques which may be applicable to the regions out of the scattering range.

GGSF FUNCTIONS SUMMARY

In-line particle diagnostic techniques can be utilized for many of the experiments. Experiments which are outside the region of the in-line techniques will have to utilize various off-line sampling for particle characterization.

In-line access ports are required for the diagnostics.

Internal mounting and interfaces for angular scattering detectors are required.

4.3.5 Imaging

The imaging requirements are not quantitatively defined in the workshop questionnaire. Based on discussions with the experimenters and an independent assessment by TRW (including state of the art in imaging, cost, size, weights, etc.), a set of tentative functional requirements has been developed. The issues which have a major impact are as follows. In general, CCD cameras approach the resolution of a photographic film, so it is **assumed** that a CCD is acceptable. The advantage of a CCD-based imaging system is that the data can be stored either digitally or as an analog video signal. In both cases the data can be transmitted back to Earth through the up/down link capability of SSF, whereas photographic film has to be saved and stored under a controlled environment (temperature, light, radiation), transported to Earth, developed and analyzed.

- *Spatial resolution. When observing a cloud of particles/droplets, is it necessary to look at the cloud as a whole or to focus and look at individual particles within the cloud?*

The required resolution and field of view (FOV) determine the size of the CCD array. Conventional CCD cameras operating in the RS-170 format produce a field of roughly 500x500 pixels. Large format CCDs, which are available in sizes as large as 4,096x4,096 (or 16 million pixels), require custom readout electronics and logic, and usually take up to several seconds for the array readout. This implies that the camera must have a shutter which opens during the exposure and is closed during the readout cycle or the illumination must be turned on and off for exposure and readout, respectively (these large arrays are usually of the "full frame" format and are not made in the "frame transfer" or the "interline transfer" formats). Thus the required resolution and FOV determine the necessary CCD format, the operating mode of the imager, the possible temporal resolution, and data rate. For the high-resolution imagers, the exposure and readout time is limited by the dark current that reduces the dynamic range and increases the noise level. Cooling the CCD array may be advisable to reduce the dark current (typically, every 7°C drop in temperature cuts the dark current by a factor of 2). Thermoelectric cooling is sufficient in this situation. A CCD can provide variable spatial resolution by changing the optics. A zoom

lens can close in on a region, and a macro lens (macro-zoom lenses are fairly standard on most home video cameras) can allow a close-up of small particles. With this approach the FOV and the depth of field become variables that are dependent on the zoom setting (i.e., focal length).

- *Temporal resolution. What frame rate is needed?*

The RS-170 standard provides 30 frames per second. Most GGSF experiments are much slower than this. It is not likely that there will be a need to continuously collect imaging data. In these cases a single frame once in a while may be sufficient. This can be accomplished with a video camera and a frame grabber (digitizer) which captures a single frame. The market has seen recently the entry of several electronic digital cameras which use a CCD array and a floppy disk to capture the data digitally. Such a camera would be most useful for the GGSF.

The situation is different for the collision experiments. If the objective for the collision experiment is to measure the particle velocity before and after the impact, a rate of, say, 100 fps (three times the RS-170) may be sufficient. If a particle moves at, say, 10 cm/s, it will be seen every 1 mm along its motion (100 mm/sec÷100 fps = 1 mm/frame). For a 1-mm particle this is fairly reasonable. Another consideration, however, is the FOV required to follow the particle. To continue with the numerical example, if the FOV is 10 cm, the spatial resolution is 100 mm÷500 pixels = 200 μm per pixel, which is adequate for a 1-mm particle. If, on the other hand, the experiment objective is to observe the impact itself, and what happens to the particle during the interaction, a very high frame rate may be required. The electronics required to drive the CCD camera at 100 fps or faster will have to be custom made. Provided the illumination is adequate, the data rate limit of the imager is determined by the CCD readout noise which increases with the data rate. For very-high-speed videos special parallel-output CCD are preferred. Another issue related to high-frame-rate imaging is the question of how to trigger the data acquisition at the right time, to avoid collecting a tremendous amount of data.

TRW's recommended functional requirements for the imaging are, hence, for a CCD camera, with a digitizer (frame grabber) and a dual logic driver (switchable by software command), one for a standard RS-170 rate, and the other for a 100 fps data rate. The camera will be equipped with a macro-zoom lens and will be mounted in close proximity to the window on the experiment chamber to provide a fairly wide FOV. A second camera at 90° to the first will be available to allow the measurement of the velocity vector of particles during the collision experiments. The illumination for the cameras will consist of "white" light with back-lighting of the scene (light shining into the camera) in one case, and front-lighting the other camera. These arrangements give flexibility for various situations, which can optimize the imaging for the different experiments.

GGSF Functions Summary

- *The imaging functional requirements include two RS-170 CCD cameras with their axes normal, one back- and the other front-lighted with macro-zoom interchangeable lens and with software-driven logic to allow frame rates up to 100 fps.*

Single-plane imaging. An alternative to the white-light illumination is the use of a thin sheet of light to illuminate a "slice" through the particle cloud. There is no loss of information with this method since the depth of field with the white-light method is not great anyway. The single plane is accomplished with a laser light source and a couple of cylindrical lenses. A HeNe laser

would be appropriate since the CCD camera has good sensitivity in the wavelength range of the HeNe. The anamorphic optics are used in two perpendicular planes, one to spread the light into a sheet and the second to focus the width of the sheet. The CCD camera views the illuminated plane in a direction perpendicular to the plane. One concern with this method, however, is the level of illumination. This depends on the laser power and the scattering produced by the particles. The CCD sensitivity is usually good, but a long exposure (say 1/4 to 1/2 sec) may be required. In the absence of major motion, a long exposure may not pose a problem. The problem may be with the dark current of the CCD, which ultimately may saturate the pixels. Cooling the CCD is definitely advised for long exposures. A more detailed analysis of the exposure and available photon flux is required.

Image analysis. It is **assumed** that one of the objectives of imaging is to provide particle count and characterization (e.g., shape). Particle characterization using imaging is a fairly common technology, and it is based on a dedicated computerized image analysis software. This is best done with a digitized image that is scanned by the software to identify the borders (closed boundaries) of the individual particles. The characteristics of these particles, such as projected area, maximum and minimum linear dimensions, etc., can be derived by the software system. The technique is limited to images in which the overlap between individual particles is minimized, otherwise it becomes difficult to distinguish between single and double particles. The technique is further limited to sufficiently high-spatial-resolution images.

Holography and holographic interferometry. Unlike a photograph, which has a shallow depth of field, the hologram captures the complete volume of the laser-illuminated chamber. The particles are counted from the reconstructed image formed by conventional computerized image analysis technique. Since the complete depth of the chamber is captured, one can perform this image analysis at different planes and obtain a volumetric particle count. The same limitation on particle overlap and spatial resolution exist, although the reconstructed hologram may be viewed from slightly different angles to optimize the analysis. The negative aspect of holography is that a highly stable environment (vibration free) is required to record the holograms on photographic plates (typically glass slides, but possibly film). The photographic plates must be developed just like any photographic negatives, which may have to be done only after returning the holograms back to Earth.

GGSF Functions Summary

- *It is this study's conclusion that neither holography nor computerized image processing are necessary as part of the space-borne GGSF.*

4.3.6 Off-Line Diagnostics

As was shown above, although the optical in-line diagnostics provide a relatively simple and fast method for determining cloud properties, they do have a limited range of parameters. To supplement these techniques and to meet additional experiment requirements, several off-line techniques are assessed. Two regions are shown in Figure 8 and are of interest here. The areas to the left and right of the in-line zone can be covered to some extent by special sampling devices, shown in Table 40.

Table 40. Off-line Sample Diagnostics

Small particles or low concentration	
Condensation nuclei counter	Require various degrees of flow rate through the apparatus and may not be compatible with a small chamber volume. May be destructive to the remaining sample in the chamber. The sample may be significantly altered in the process.
Electrical mobility analyzer	
Diffusion battery	
Large particles and high concentration	
Imaging	*In situ* technique
Sample collection on filters	Require a relatively high flow rate to deposit particles on filter or impactor plates. Same considerations apply as above.
Sample collection on multistage impactors	

With the exception of imaging, all the techniques require sample removal from the experiment chamber. A second requirement with all these techniques is that a continuous flow (of various rates, depending on the technique) is established. As a result, the experiment may suffer major interference due to the sample removal. For experiments performed in vacuum this may be impossible.

4.3.7 Experiment-Specific Diagnostics

Access ports should be available for mounting in-chamber experiment-specific diagnostics hardware (see Tables 24 and 25 for requirements). It is anticipated that the experimenter will supply the design or concept for these special diagnostics not provided as a part of the facility.

4.3.8 Calibration

The issue of absolute and relative calibration of the GGSF instruments falls under general and similar requirements for all other SSF-borne instruments. The S&T requirements should specify, when applicable, whether absolute or relative calibration of instruments is required. The general issue of calibration of instruments on-board is to be addressed as a generic issue for all payloads.

4.4 Positioning/Levitation

4.4.1 Particles' Kinematics Under μ-g Conditions

The purpose of this section is to review the background to, and the rationale for, a positioning/ levitation requirement. Particle dynamics due to residual gravity (see Appendix E and section 4.1.2.4) and to diffusion (section 4.1.2.4) limit the experiment duration on board an orbiting platform. Whereas on Earth, the gravitational sedimentation time is very short, limiting most experiments, some GGSF experiments require an extended duration (see section 2.7.2) which is longer than the sedimentation (or diffusion) time in orbit. The rationale behind the "levitation" requirement is that in such experiments particles could be kept in the center of the experiment chamber by means of the levitation system, thus extending the time available for the experiment. The rationale behind the "positioning" requirement is to enable the placement of a particle at a selected location in the chamber. For instance, for a collision experiment, the two colliding particles should be positioned accurately to effect a collision and to allow observation of the

event with the imaging system (see section 2.5.10). The discussion in the following sections distinguishes between the levitation, positioning, and manipulation requirements.

In the following section the levitation technologies and their applicability to the GGSF are reviewed.

4.4.2 Levitation Technology

A fairly comprehensive review of the levitation technology was performed for NASA/ARC under a contract by the Martin-Marietta Astronautics Group (MMAG).[37] The report reviews the different levitation technologies and discusses the feasibility and applicability of the technologies for the GGSF. TRW performed an independent assessment and has reached the same conclusions. The key relevant MMAG conclusions are briefly discussed first (for details, refer to the original report), and the approach recommended by TRW for limited types of applications is discussed in section 4.4.3.

> "All levitation techniques either produce artificial coagulation, ordering, or other effects that adversely affect cloud experiments. Therefore, whenever possible, cloud experiments should not use levitation but should be performed in a chamber with inactive walls (e.g., Teflon). The chamber should be as large as possible in order to reduce the surface to volume ratio and thereby reduce contamination from walls."

The MMAG study concludes that it is not possible to levitate a cloud in its dispersed form. All levitation techniques tend to move the levitated object to a focal location (energy well) and if used with a cloud of particles, all the individual particles in the cloud would move in the direction of that energy well. This would accelerate particle interactions and affect the outcome of the experiment. Hence, it is not feasible to move the cloud as a structure without affecting the individual particles. The suggestion of a Teflon wall implies coating the wall with material such that it will no longer act as a "sink" for particles, allowing particles colliding with the wall to bounce back. This would eliminate the concentration gradient associated with the wall which ultimately creates a diffusional motion of particles toward the wall.

> "Levitation is useful for the study of optical properties of a single particle after it has been nucleated in the large chamber. It may be possible to levitate this single particle during continued growth. Levitation would be performed in a small separate chamber. Electrostatic levitation is a well-established technique that is probably the most versatile with respect to particle size and composition."

This conclusion can be summarized by saying that single particles can be levitated (as opposed to clouds) and that levitation may be used for positioning purposes for photography or other measurements to be performed on the particle.

In reviewing the levitation technology, two systems have been identified as the most mature for the largest number of experiments. These are the acoustic and the electrostatic techniques. Both have been extensively developed by JPL and have been developed into flight hardware. The JPL systems have been tested in μ-g both in space flight and on board the KC-135.

Before further discussing these techniques, it may be useful to briefly touch upon some of the other available levitation techniques often described in the literature. In general, all of these

[37] J.B. Miller, B.C. Clark. Feasibility Study for the Gas-Grain Simulation Facility. NASA CR 177468, September, 1987.

techniques, which have been shown to work in the laboratory, can be implemented in the GGSF. TRW's assessment is based, however, on the universality of the technique (i.e., not limited to one specific experiment only), the engineering development complexity (a somewhat subjective assessment), and the impact on the overall complexity of the GGSF.

The "light" levitation uses the momentum exchange between photons and the particle to move the particle. Since the momentum of a single photon is very small, a focused laser beam is used to provide a sufficient momentum flux on the particles. The exchange of momentum depends on the optical properties of the particle (i.e., the complex index of refraction), particles which reflect or transmit the light react differently. This technique suffers from the following deficiencies in relation to the GGSF:

- The laser power required to move large particles may be excessive given the SSF limitation; this includes the laser auxiliary equipment such as power supply, cooling flow requirements.
- With the exception of small, low-powered HeNe lasers, other lasers would require an extensive technology development program to miniaturize.
- The technique is not universal for all types of particles because of differences in optical properties of various particles.
- It is not always clear which way is "down" and the laser-light levitation works only along the beam axis, or else the beam has to be transmitted in different orientations.
- Particles which exhibit significant absorption of the light may heat up to an unacceptable temperature level, or even burn.

Radiometric levitation relies on preferentially heating the particle on one side. This changes the kinetic energy and momentum exchange between the particle and colliding gas molecules, leading to a motion similar to thermophoretic. The deficiency with this technique is that it heats the particles which alter their properties. Further, in the absence of gas molecules such as in vacuum experiments, this technique would not work. Hence this technique is also limited to certain experiments and is not universal enough for a facility.

Aerodynamic levitation is based on blowing a gas stream which applies drag force to the particle in the direction of the gas motion. This technique is very difficult to implement for very small particles because of aerodynamic instabilities. It also works only along the jet axis and can not be easily reoriented if the particles move laterally relative to the aerodynamic axis. Further, this technique can not be applied in the vacuum experiments.

Acoustic levitation is fairly mature technology, but it does not work in vacuum. Electrostatic levitation, also well developed and works well with one and probably two particles. Both these techniques utilize fairly complex imaging systems with feedback control systems to stabilize the particle in position. It is not clear how well these techniques would work with the very small particles (μm size) as opposed to the classical millimeter-to-centimeter particles which are currently utilized.

In conclusion, the requirements for the use of levitation needs further study. Specific experiment categories may benefit from particular levitation techniques and depending on the S&T requirements and the maturity of the technology some of these techniques may be accommodated in the mature facility configuration.

GGSF FUNCTIONS SUMMARY

In spite of the present status of the various levitation techniques discussed so far and their flight experience, the technology to position particles of all sizes under various pressure and temperature conditions is still experimental in nature. The GGSF, as envisioned presently, has a number of difficult tasks and technologies to deal with. The added complexity, weight, size, and the need to rely on yet another, not-totally-proven technology, is the basis for TRW's recommendation not to make levitation a part of the core GGSF design.

It is further recommended that the experiments should perform the required analysis/modeling and develop an approach to compensate for the loss of particles by controlling the initial experiment conditions and environment in order to accelerate the phenomenology under investigation (and thus avoiding the need for levitation).

It is also recommended that statistical observations of a single particle out of a cloud may be substituted for observations of a single particle which must be positioned or levitated.

Levitation could be added at a later time to the GGSF if the technology reaches a point of maturity and the need can be justified.

4.4.3 Single-Particle Electrodynamic Levitation and Positioning

Two approaches are proposed for this purpose. One is based on active positioning and levitation of a single particle under very specific conditions, and the other is based on a positioning without active levitation which, again, may have some limited application.

This discussion follows the rationale and logic in the previous section. It deals primarily with a situation in which it is absolutely necessary to position and keep a single particle in place. The solution recommended here is an experiment-specific hardware that requires development and testing under various conditions such as particle size, particle material, pressure, temperature, etc. The method is based on a modified version of the Millikan electrodynamic balance which was used to measure the charge of an electron. The method was further developed by TRW in the late 1950s[38] and used recently by the author of this report.[39]

As compared with the other levitation systems, this is an old and proven technology. The chamber in which the particle is levitated is cylindrical, typically no larger than 10-cm in diameter and about the same length. Active control of the particle position is possible, and the technique may be used for the **measurements of the particle mass and electrical charge**. About half a dozen particle injection techniques were tested during the investigation discussed in the latter reference and a satisfactory solution was found for particles in the range from a few tens

[38] Wuerker, R.F., Shelton, H. and Langmuir, R.V. J. Applied Physics, 30, 1959, 342.

[39] Gat, N. (program manager) Final Report; Kinetics of Coal Combustion. Part III: Mechanisms and Kinetics of Char Combustion. Chapter 6 Electrodynamic Thermogravimetric Analyzer, pages 258-294. Authored by Gavalas, G.R., and Flagan, R.C., Caltech. September, 1988. Work performed under DoE contract number DE-AC22-85PC70815.

μm to several hundreds μm. The electrodynamic balance could be inserted into the experiment chamber for those experiments which can utilize this technique. The experiment chamber provides internal mounting points and electrical interfaces for specific hardware.

A second solution to the positioning of particles and droplets is based on the inertial technique. This approach was successfully developed and tested in the laboratory by the author of this report and finally implemented in TRW's design for the Droplet Combustion Experiment (a NASA/LeRC sponsored μ-g combustion experiment). The technique works well with particles of the millimeter size and may not work with the μm size particles, though. It is based on detaching the particle from a mechanical holder by rapidly pulling the holder away. The inertia of the particle basically holds it in place. The hardware, built and delivered to NASA/LeRC, has been in operation in the 0-g Facility for the past several years proves that the technique is very successful under the right circumstances, and may work well for the GGSF. But this technique cannot be considered universal for the broad requirements of the GGSF and should be considered experiment specific.

4.4.4 Collision Experiments Methodology

Particle acceleration. One of the arguments for performing some of the GGSF experiments in orbit is that agglomerates and fractal particles are often too fragile to survive Earth's gravitational field. The maximum acceleration a fragile agglomerate or a fractal particle could withstand is not yet known, nor is it specified in the S&T requirements. In the collision experiments it is necessary to accelerate aggregates and small particles (down to the 10 μm) to tens of centimeters per second. In order to accelerate a particle to a velocity V, over a distance, S, (which is limited by the chamber size and the "aiming accuracy," the acceleration experienced by the particle is $a=V^2/2S$, or in terms of the number of g's , $\alpha=V^2/2gS$. Thus to accelerate a particle in a 10-cm distance to, say, 50 cm/sec, the particle would experience about 0.1g's.

Stopping distance. In two of the collision experiments (2 and 4) the chamber pressure covers the range from low vacuum to 1 bar. A particle accelerated to a velocity, V, moving through an atmosphere, is decelerated by aerodynamic drag. The analysis of the stopping distance for the relevant particles is given in Appendix E and summarized in Figure 24. In general, for the μm-size particles (Exp. 2) this stopping distance is of the order of a few cm at most (depending on the pressure and the particle's ballistic coefficient, m/C_dA; here m is the mass, C_d is the drag coefficient, and A is the frontal area of the particle). For the large particles (Exp. 4) the stopping distance would be of the order of a meter and this is not a problem. The third collision experiment (Exp. 1) is in vacuum and aerodynamic drag would be negligible.

Another effect, which may prevent collisions in some situations, is observed when two particles approach each other in an atmosphere of gas. The motion of one particle creates a flow of gas ahead of the particle. When this flow encounters another solid body (a second particle or a surface) one of two things may happen. If the second particle is small, it would start moving in the flow direction and the first particle may never collide with it. If the second particle is relatively large (high inertia), it will not move much, but the incoming flow would experience a stagnation point and would deflect around that object. The first particle may then follow the stream lines and altogether miss the object. This principle is used in impactors to separate large particles (which cross the stream lines and impact on the "target") from small particles (which follow the stream lines and remain airborne). This effect may be relevant to experiment 2 in which small particles are utilized at the near-atmospheric-pressure range.

Aiming accuracy. For a 10-μm particle to hit a similar size particle from a distance of 10 cm, the margin of aiming error is less than 0.1 milliradian. It is difficult to conceive of a method for accelerating a single 10-μm particle with this level of accuracy. Further, the acceleration mechanism must not produce any disturbances in the atmosphere which could divert the particle from its trajectory by that amount. And, finally, the deflection due to gravitational sedimentation during the particle travel time must be smaller than the required aiming accuracy.

Particle injection. In light of the issues discussed above, what are the possible solutions? For the relatively large particles (Exp. 4) it is possible to mechanically "push" the particles either by blowing them through a tube (a "gun barrel"), or pushing them off the tip of a rod. These particles have sufficient inertia to overcome any adhesion and cohesion forces between the particle and the pushing mechanism. The small particles will be more difficult to push mechanically. The adhesion forces may be larger than the inertia of the small particle, and they may not separate from the mechanical device. Other techniques may be required. Possible approaches include charging the particles and accelerating them in an electrical field, or charging a wire coated with the fine particles to a high voltage causing repulsion.

An alternative to conducting collisions between single particles should be investigated. One possible approach is to blow a large number of particles toward a cloud of stationary particles and observing collisions on a statistical basis.

GGSF Functions Summary

Particle collision experiments would require experiment-specific hardware which depends on the particle size, pressure range, allowable g-loads, etc. More development and testing of various techniques may be required before an engineering study can proceed further.

Issues such as stopping distance, particle inertia, and injection mechanisms must be thoroughly assessed to determine if the collisions are possible. Experiment-specific hardware will have to be developed for different particle sizes.

4.5 Gas Handling And Storage

4.5.1 Gas Mixture Supply Options

The facility requirement is to provide the required gas mixtures for the experiments. Several options are possible to accomplish this function, each has a major impact on the overall facility design and science.

A. Premixed Bottled Gas. With this approach the GGSF carries *n* cylinders of premixed gases prepared in advance on Earth for a particular set of experiments. The gases in each cylinder may be filled so that when the cylinder is opened into the chamber, the right pressure is obtained. Alternatively, the cylinder may have enough gas for several experiment repeats.

Advantages

- Simplest method to implement.
- Avoids complex operations required in preparing the mixture on board which includes precise metering.

- Maximizes the gas utilization since there may be very small volume between the cylinder and the experiment chamber.
- Eliminates a bulky, heavy mixing chamber with the associated valves, controls, meters, etc.
- Reduces the experiment timeline since gases are filled in a very short time.

Disadvantages

- Provides the least flexibility to change the mixture composition for subsequent experiment based on unanticipated results.
- May require many bottles if the experiment is to be repeated with various compositions.
- Separation of gases and chemical reactions over long storage periods.

B. Mixture Preparation in Experiment Chamber. With this approach, only pure gases are carried in the bottles. Mixtures are prepared by metering the various gases into the experiment chamber. The mixture composition and moisture can then be verified by withdrawing a small sample into the gas chromatograph for analysis. There are several issues related to the preparation of precise mixtures of gases.

- Gases do not tend to mix very well in a short time; in fact it may take a day or more for the mixture to homogenize by diffusion only. Some mechanical mixing (e.g., fan) may be required.
- Since the different gases flow into the chamber at different pressures and temperatures, it is not possible to utilize flow metering which is accurate enough to the required level. Metering must be accomplished by a slow fill of the chamber and the monitoring of the partial pressure as each gas is added. This process contributes to the initial poor mixing of the gases.
- When gases are released from high-pressure storage cylinders, they undergo rapid expansion and cooling, reaching the chamber at a temperature different from the ambient. Monitoring the partial pressure is misleading under such conditions, and it is necessary to wait for thermal equilibrium before an accurate assessment of the pressure can be made. This process can take a very long time since free convection virtually is nonexistent and heat transfer is by conduction through the gas (a poor heat conduction media).

Advantages

- Provides flexibility in selecting mixing composition.
- Eliminates mixing chamber with most of the associated plumbing, etc.
- Good utilization of the gases in the bottles since only small plumbing volume exists between the bottles and the experiment chamber.

Disadvantages

- Prolongs the experiment timeline since mixing is now required for each experiment and repeats.
- Chamber design may be complicated if a mixing fan is introduced.
- Requires the ability to inject water for those experiments requiring controlled amount of humidity.
- Usually the repeatability in mixing is no better than ±0.5%, and expected to be even worse under orbital conditions.

C. Combination of A and B. With this method, premixed bottles are carried plus a few small cylinders of pure gases. The pure gases are used for minor changes in composition.

Advantages

- Both advantages of the combined A and B above.

Disadvantages

- Allows only minor correction in composition.

D. Using a special mixing chamber. With this approach, only pure gases are carried. Mixtures are prepared in the mixing chamber from which the experiment chamber is refilled. The mixing of the gases in the mixing chamber follows the same procedure as described in B above, but a mixture can be prepared for several repeats of the experiment. The sizing of the mixing tank is based on the number of experiment chamber refills desired in one mix operation. If a mixture is prepared for n experiments, and the volumes of the experiment chamber and that of the mixing chamber are, $Vexp$ *and* V_{mix}, respectively, then the mixing chamber pressure is $P_{mix}=P_{exp}\cdot n\cdot V_{exp}/V_{mix}$. The trade-off is between the mixing tank volume and pressure.

Advantages

- Reduces experiment timeline since several fills can be mixed in one time.
- Assures uniformity of the mixture for experiment repeats.
- Transfers some of the mixing functions from the experiment chamber to the mixing chamber, simplifying the design of the experiment chamber.

Disadvantages

- Requires a special tank which adds volume, weight, controls, and complexity to the facility.
- Creates underutilization of the stored gas since a large volume exists between the storage bottles and the experiment chamber.
- Limits the stored gas utilization if the mixing chamber pressure is too high.

The mixing chamber would require ports for gas fill, gas chromatograph line, humidity sensor access, water injection inlet, pressure gauge, a vent line, and a mixing fan interface.

GGSF FUNCTIONS SUMMARY

GGSF is to provide gas mixing and humidity control capability for the experiments.

A better understanding of the experiment requirements in terms of gas mixture composition, number of repeats, and possible variations in composition for the repeats is needed to make the proper selection of a gas mixing supply system.

The mixing control accuracy can, in general, be achieved with the accurate measurement of the pressure, temperature in the mixing chamber, and the proper accounting for the compressibility factor of the gases.

Moisture composition can be controlled by the careful metered addition of water into the mixing chamber. The required verification accuracy is beyond the performance of conventional humidity meters. The use of the GC may help to determine more accurately the water mole fraction. Since no temperatures were specified with the relative humidity requirements, e.g., at room temperature or at the experiment temperature, the former is assumed.

4.6 Storage

GGSF may require extensive storage space if all the interchangeable hardware and special tools are to be kept on board, and it would not be unreasonable to suggest the addition of another single rack for that purpose. Under the present scenario, however, this option is not considered. What's more, based on initial layouts prepared by TRW (see the Stage 2 -- Conceptual Design Final Report), the GGSF subsystems seem to occupy the majority of the ISPR's available space. Therefore, the approach proposed is to define, as a facility functional requirement, the allocation of a specific volume for storage. The size of that volume is yet to be determined, and it would depend on a better understanding of the specific requirements as discussed in the following subsections.

4.6.1 Sample Pre- and Post-Experiment Storage

It is anticipated that during the initial facility operating period, at MTC, maximum automation and remote control will be required. No operator will be around to move the pre-test samples from storage to the sample generator. It is desirable, therefore, to attempt to integrate the sample generator with the required pre-test storage for the sample materials (see section 4.2.2).

Pre-test sample storage. Some of the sample material will be actually stored within the sample generation system. For instance, liquids for aerosols may be stored in a bladder which directly feeds into the liquid atomizer. More than one liquid type can be attached to the atomizer so that no special storage is required for liquid samples. However, if the atomizer must be cleaned before it can be used with another liquid for a new experiment, the whole atomizer assembly may have to be replaced between experiments.

Solid powders for multiple experiments, likewise, are **assumed** to be loaded and stored in the particle disperser and require no special storage. The disperser should have the capability to select one sample batch out of several available batches, and to disperse that sample into the experiment chamber.

Other types of sample generation can also be designed for automated operation in a similar fashion. The soot generator, for instance, can contain the fuel or other reactants required for the combustion in an attached vessel feeding directly into the generator.

Post-test sample storage. This issue is somewhat more complex than the pre-test sample storage. First there is the issue of sample removal and/or collection (see section 2.5.2), and the second issue is related to the storage of the collected samples. The former issue has direct relevance also to the issue of waste management (sections 3.3.3 and 4.7).

Sample removal and collection can ideally be performed via the use of conventional filters or impactors. The only difficulty is when the sample in the chamber is in vacuum, then it is not clear how to remove and transfer the sample into the filter. One option is to fill the chamber with an inert gas (e.g., GN_2) to atmospheric pressure and then to collect the carrier gas, using the vent vacuum suction, into a filter which collects the liquid or solid particles.

Once the sample is collected, the filter substrate is to be stored and return to Earth. This function may be performed *in situ* (i.e., diverting the flow from subsequent experiments into another parallel filter and preserving the sample in the filter holder), or by actually removing the filter from its housing (filter holder) for storage. As with the sample formation, a desirable feature

would be a sample collection device with a capability to collect several different samples and preserve their identity.

The requirement for special fragile samples (fractals and agglomerates), as well as for samples which require special environmental control (e.g., temperature, humidity, etc.), are experiment-specific.

GGSF FUNCTIONS SUMMARY

Pre-test sample materials are to be stored integrally in the sample generator for MTC, or should be easily loaded into the generator for PMC.

Post-test sample collection function should be capable of collecting small particles, droplets from the chamber over the range of operating pressures, preserve the identity of the individual samples, and prevent any form of sample interaction with the cabin atmosphere.

Experiment-specific sample storage requirements, such as for fragile structure and samples requiring thermal control, are to be defined.

4.6.2 Other Storage Requirements

The GGSF may need to provide storage location for special tools required for the removal and installation of any of the interchangeable subsystems, and for spare parts such as light bulbs, and other components. In addition, there is a requirement for the storage of experiment-specific hardware. Examples include condenser plates to apply electric field, ultrasonic apparatus to determine shear strength of fractals, apparatus for the determination of mass of aggregates. Additional storage may be required for waste storage canisters and filters.

4.7 Waste Management

Waste management requirements are driven by the SSF's gas and particle allowable disposal specification (section 3.3.3). All experiment-generated waste, including gas and particles, must be cleaned to the required specification before dumping into the waste and vent lines of the SSF. The alternative to using the SSF vent is to store all such waste within the GGSF. For obvious reasons, this approach is unacceptable. First, GGSF would require a special compressor to compress such waste into a smaller volume, or else, a very large volume waste tank is required. The approach to waste management is based on replaceable filter and sorbent beds. Waste management system health monitoring is required for verification that the system is not plugged up. In addition, some of the removal mechanisms may involve exothermic reactions and an active cooling of the canister may be required.

4.7.1 Particulates Removal

In general, inorganic particulate matter removal can be accomplished by using the appropriate filters. Based on Figure 21, only particles larger than 10 μm must be removed. No requirements were identified for particles smaller than 10 μm. In general, filters are optimized for a specific flow rate such that the particle velocity through the filter is neither too high nor too low. Since,

the GGSF will be operating over a range of pressures, it is not always possible to generate the required flow rate through the filter (e.g., when the chamber is at vacuum). There are two ways to withdraw the chamber contents through the filter. First, by opening the system to the SSF vent line, and second by including a circulating pump or fan in the line. If a single pass through the filter is sufficient to remove all particulate matter to the acceptable level, than the former approach is acceptable. If, however, it is necessary to recirculate the flow through the clean-up system more than once, or if the pressure drop through the filter system is too high, a circulating pump will be required.

Another requirement is the monitoring of the filter conditions. As the filter collects more particles, its separation efficiency drops while the pressure drop for flow through the filter increases. A monitoring system is required to monitor the state of the filter and to divert the flow to a new filter (or alert the operator to replace the filter) when necessary.

For experiments in which the chamber is at a very low pressure, the use of GN_2 to fill the chamber to an initial pressure that allows the filtering system to operate efficiently may be required. Such an approach may even be required for experiments that operate at atmospheric pressure since a continuous flow will be required until all the chamber contents is vented. In fact a flow equal to several volumes of the chamber may be required to assure the complete venting of the chamber.

Organic particulate matter may be treated as the inorganic material, or it may be treated by catalytically converting it to gaseous compounds.

For an efficient removal of all the particulate matter, the filter is likely to consist of several stages which may include an initial layer of a coarse filter (e.g., compressed fiberglass sheet), a packed bed of small mesh-size activated charcoal for trapping organic materials, and, finally, a fine filter media for the very small particles down to the 10 μm or below.

4.7.2 Gas Scrubbing

A specific analysis of the expected waste composition, the quantities of the various compounds (based on the experiment schedule), should be performed in order to develop an appropriate concept for the gas scrubbing system. In general, however, the gas scrubbing materials fall under the categories of impregnated charcoal bed for the removal of hydrocarbons and basic gases, LiOH for the removal of acid gases (if these exist) and catalysis for the oxidation of CO and H_2. Other beds may be required for specific materials. All of these chemical beds can be housed in a single canister assembly or individually.

4.7.3 Vent and Waste Line Management

The vent and waste line management is primarily concerned with timelining the waste removal from the GGSF with respect to other payloads that may use the same vent and waste lines. The concern is that when other payloads use the waste line and the GGSF system attempts to utilize the line at the same time, cross contamination may occur, and waste may flow upstream into the GGSF. This means that the removal of waste from the experiment chamber must be coordinated and can not happen at random. The coordination is performed by the payload computer that communicates with the SSF DMS. The payload computer must also monitor the state of health of the waste management system and alert the operator when the sorbent/filter canister must be replaced.

4.7.4 Waste Storage and Containment

The GGSF may provide storage for a replacement canister and for the spent canister which must be returned to Earth for disposal.

4.8 High-Vacuum Chamber Considerations

All but one of the experiments in the workshop questionnaire can be accommodated with a vacuum level of 10^{-6} bar, a level provided by the SSF. In one experiment, a pressure level of 10^{-8} to 10^{-10} bar was requested. To meet this requirement a special high-vacuum pump would be needed. Appendix D, Figure D-1 shows a list of appropriate vacuum pumps for low pressure.[40] Turbomolecular pumps may work well provided a pump with magnetic bearings is selected. Turbomolecular pumps are very small, noiseless, and vibrationless, and they operate at speeds of up to 50,000 RPM. Space vacuum, provided through the SSF, serves as a good roughing pump for the high-vacuum pump.

The use of high vacuum raises other issues in relation with various interdependent subsystems.

Chamber design. The chamber, connectors and all other interfaces that are to be exposed to the high-vacuum level must be specially designed for that purpose. Seals are typically metallic (no elastomers may be used), and components and parts may have to undergo a **bake out** to remove moisture and residual volatile matter. Further, if the chamber is exposed to the atmosphere, moisture will build up a molecular monolayer which will continue outgassing for a very long time unless the chamber undergoes another bake out. This implies that the chamber should never be exposed to the cabin atmosphere, which precludes a modular approach to the facility. In addition, the chamber may not accommodate other experiments in which condensables (including water) are used.

Another issue is the pumping-down time. To make this time reasonable, the conductance between the chamber and the pump must be sufficiently high. This implies a flange size that is typically as large as the chamber diameter. Not only is this configuration incompatible with all other optimal functional requirements for the other experiments, it will also preclude the cooling of this chamber because of parasitic heat loss. Experiment 17 not only requires the high vacuum but also requires the lowest range of temperature, down to 10 K (with 4 K desired).

It seems that the only way to accommodate experiments of this class is to use an experiment-specific chamber that is as small as possible (e.g., 2 to 3 cm in diameter). This will make both cooling and pumping down the pressure much easier. The problem is that this geometry will probably not provide sufficient experiment time since the particles in total vacuum are in free "fall" and even at 10^{-6} g will fall to the bottom of that chamber in a few seconds. This point holds also for larger chambers. The available experiment time increases only like the square root of the chamber dimension. Thus no more than a few seconds to a minute are available for a high-vacuum particle experiments, in any case.

An additional issue is the hazard of particles getting into the 50,000 RPM pump. This may not only cause damage and erosion of the pump blades, but also result in a catastrophic pump failure.

[40] Product and Vacuum Technology Reference Handbook, Leybold-Heraeus, Vacuum Products, Inc.

A further difficulty in maintaining such a high vacuum is related to the experiment materials themselves. For instance, experiment 17 uses ices of water and other gases. The vapor pressure of these substances is much higher (even in the solid phase), causing the material to evaporate/sublimate very rapidly. This sublimation will rapidly increase the pressure in the chamber above the specified range.

A final difficulty with the high vacuum is the introduction of the experiment sample into the chamber. If the sample must be introduced with a carrier gas, the vacuum is lost and there is no way to pump the carrier gas out while leaving the sample in the chamber. If the sample is introduced without a carrier gas, but with some finite initial velocity, all particles will continue their motion to the wall (no stopping force acts in the absence of drag) and will be lost there.

GGSF Functions Summary

- *Based on considerations such as custom chamber design, incompatibility with other experiment requirements, sample introduction issues, available residence time, and other considerations, it seems that the requirement for high vacuum beyond the SSF-supplied μbar poses an unwarranted level of difficulty, which even if undertaken may not meet the experiment objectives.*

4.9 Electrical Power

The SSF provides its payloads with 120 Vdc and each payload performs the required power conversion. Based on a preliminary assessment of the GGSF power requirements, it is estimated that 3.0 kW will be required at the peak (the majority of the power is required by the cryocooler). 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. The primary conversion unit should be centralized for better efficiency, and in order to permit effective shielding of the conversion by-products for effective EMI/EMC suppression. The primary conversion is expected to be approximately 1,500 watts peak, A secondary conversion for the cryocooler is expected to be 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. Further, being a separate unit would minimize thermal coupling to the primary voltage source. Figure 26 summarizes the power management subsystem with the applications.

4.10 Control and Data Handling

4.10.1 Experiment Control

An overall block diagram of the GGSF electronics subsystem is shown in Figure 27. The subsystem is shown to consist of two general elements. The first element includes those components that are interchangeable and support/control other interchangeable hardware modules such as sample generators, 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 images 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.

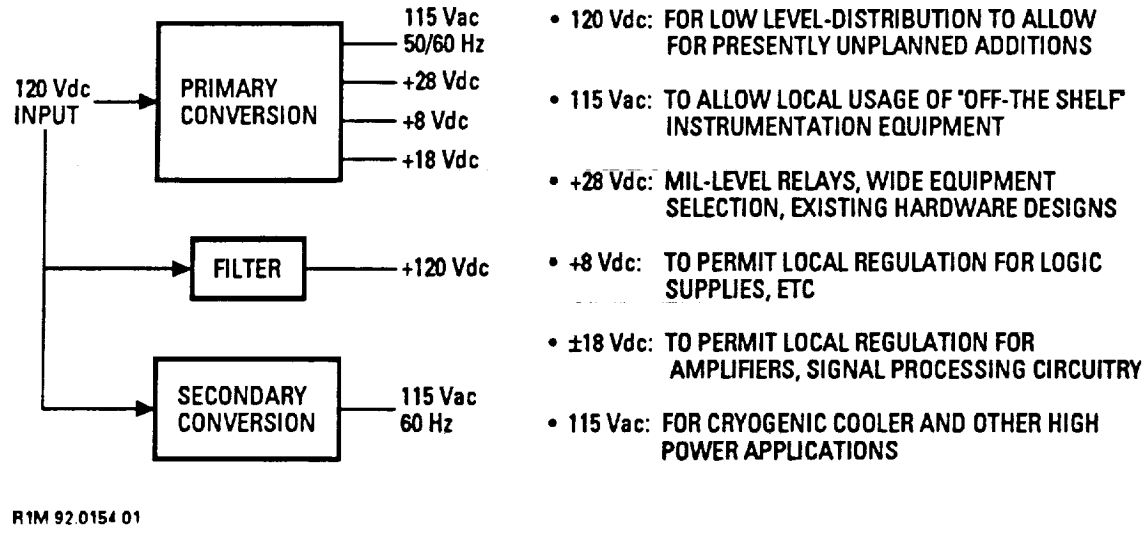

Figure 26. GGSF Power Management Subsystem

Because of the longevity requirements of the GGSF, a **modular payload computer system** is recommended. The microprocessor evolution is expected to continue to double the CPU speed every 4 to 5 years as in the past decade. It is recommended, therefore, to build in a capability to upgrade the CPU in the system as necessary. In addition, various types of I/O 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 could be independent plug-in boards that are installed into a passive-backplane- configured system as required by the experiments.

4.10.2 Data and Control Requirements

Table 41 summarizes the data handling, storage, and control requirements.

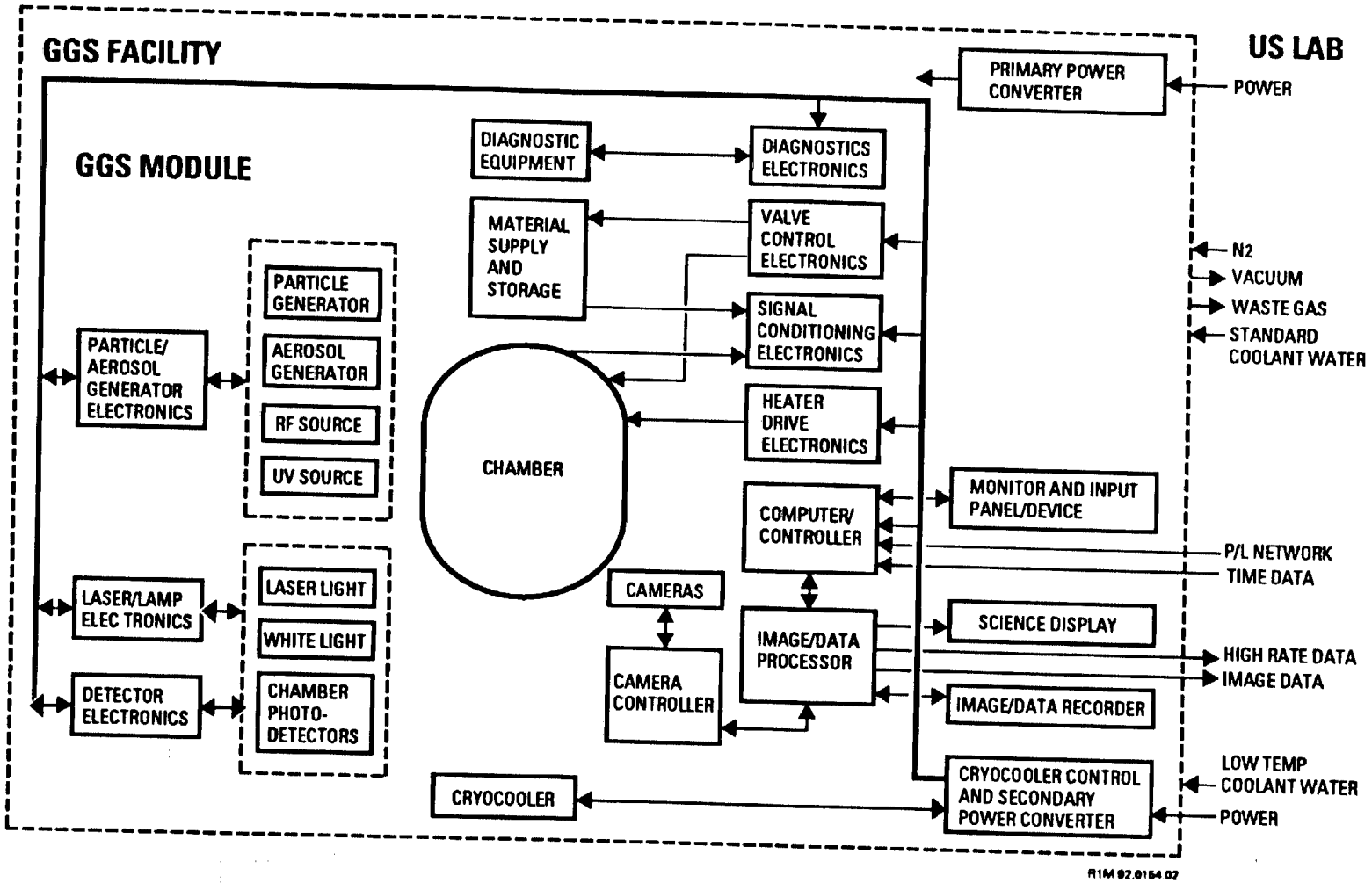

Figure 27. GGSF Electronics Block Diagram

Table 41. Control and Data Requirement

Subsystem	Sensor	Command
Chamber	Pressure, temperature	Cryocooler, heaters, valves
Sample Generation	Pressure, temperature,	Valves, on/off switches, ignition (for soot generator), TBD
Diagnostics	Optical detectors, position control sensors for monochromator grating, and filter wheel	Radiation sources on/off, mirrors in/out position, filter wheel position, monochromator scan,
	Sensor output	Off-line diagnostics instruments on/off
	CCD cameras output	Cameras on/off, lighting on/off, zoom, focus
	Accelerometer subsystem output	on/off
Gas storage & mixing	Pressure, temperature	Valves on/off, mixing fan on/off
Waste management	Pressure drop, temperature, TBD	valves on/off
Command & data handling	Facility status monitoring (TBD), communications with SSF DMS, safety status sensors TBD	Power on/off, data I/O and downlink, I/F with U.S. Module, experiment initiation and termination, data acquisition and storage
Sample collection and storage	Temperature, TBD	Sample retrieval, storage conditions TBD
Storage	TBD	TBD
Electrical power	Temperature, voltages, current	Power on/off, TBD
Environmental control	Instruments and subsystems temperature and status (TBD), cooling water flow rates, TBD	Cooling, heating, avionics air, water flow

4.10.3 Data Storage Requirements

Most of the GGSF experiments are conducted over a prolonged period of time (i.e., minutes to weeks, see section 2.7.2). The type of data collected will include temperature and pressure measurements, sample diagnostics, gas chromatograph analysis, etc. A low-rate digital data recording capability would suffice for these instruments. The video signal can be treated in two ways. Analog RS-170 data can be recorded on an analog tape (e.g., VCR) and transmitted to Earth according to a timeline schedule. The other option is to digitize the video signal using a frame grabber and to store the digital signal for downlink. Currently, only standard RS-170 video can be recorded as standard analog video data. A high-resolution- or high-speed-imaging system may be digitized. The data rate and storage requirements for the imaging system will set the GGSF data handling requirements. The technical requirements for imaging are not clearly defined, and as indicated in Section 2.6.2, the required parameters include spatial and temporal resolution, data frequency, and whether analog video is sufficient or digital data are required (and the dynamic range for the digital data). The following is an example of the impact of such requirements. Assuming an upper limit such as a 1,000 x 1,000 pixels imager, acquiring data at 100 frames per second, which is digitized with an 8-bit resolution, the total data rate is 100 Mbytes per second, and storing 5 seconds of data would require 500 Mbytes. With the present

state-of-the-art technology these requirements can be met using either digital tape drives or optical disks but at a great expense.

4.10.4 Communications with U.S. Module and SSF

The modular computer will have the required interface capabilities to communicate with the U.S. Module and the SSF data management system (DMS) via a MIL-STD-1553 and a fiber optic FDDI buses.

4.11 Structure

4.11.1 Rack and Support Structure

The rack design is provided by the SSF program. The additional support structure required for the GGSF will be compatible with the ISPR accommodations. Any rack structure modifications requirements are TBD.

4.11.2 Optical Bench

Certain elements that require optical alignment, such as diagnostics and illumination sources, may have to be mounted on an optical bench so that they can be interfaced with the various chambers with a minimum disturbance to the alignment of the system.

4.12 Housekeeping Requirements

The first requirement is for a "health monitoring/self-check" capability in which the health and status of various subsystems are monitored (e.g., gas cylinder pressure to keep track of the remaining gas).

The second requirement is for control methods to prevent "forbidden states" of valve combinations; e.g., if an attempt is made to open a combination of valves which could cause the dumping of all stored gas into the vent. The third requirement is for checklists which must be responded to after a configuration change to verify that the system is operational (and safe).

Additional requirements include approach to:

- Emergency shutdown procedures
- Stay alive mode - safing procedures
- Procedures for check and power-up after emergency shutdown
- Status check after any anomalous condition
- Routine and emergency facility subsystems, etc. changeout procedures
- Maintenance procedure, routine and other, etc.

5 MISSION REQUIREMENTS

5.1 Maintainability and Serviceability

The GGSF will have a lifetime of over 10 years and will remain operational for this period of time. The facility will be in continuous operations during this time with downtimes for chamber and other subsystem changeouts. The GGSF will be serviceable in that major subsystems can be changed and the overall facility modified. The number and variety of experiments requires that the facility be designed in a modular fashion such that the individual subsystems can be replaced.

5.2 Mission Operations

The GGSF will be one of the initial facilities that are accommodated on SSF. It will operate in two different modes. The earliest operations are in the MTC where there is no permanent crew present. It will continue operations during the PMC. The two phases require different operating methods.

- In the MTC phase experiments any facility must operate in a totally automated mode for 90 days, minimum, and perhaps for up to 180 days.
- In the PMC phase experiments any facility operation will be assisted by the presence of the crew who can expedite changes and can readily adapt to changes in the preprogrammed operating scenario.

Timelines for two of the typical proposed experiments have been prepared. These are experiment 14 (Titan Atmosphere Aerosol Simulation), Table 42, and experiment 16 (Studies of Fractal Particles), Table 43. These experiments have been refined so that preliminary timelines could be generated. These timelines qualitatively illustrate the operations and procedures, the measurements, apparatus and instrumentation that are required, the types of data expected in each phase, and the power sources that are required. The crew requirements are currently undefined; however, the availability of the crew will drive the experiment versatility. The operation periods are experiment-specific but can be divided into: (1) preparation and establishing initial conditions, (2) conducting the experiment, and (3) terminating the experiment.

These timelines are analyzed to determine experiment requirements on mission operations and to assess performance during MTC and PMC. MTC operations demand automation with well-defined experiment sequences (automation is discussed in section 5.3 below). Two main requirements are considered for experiments 14 and 16 relative to automation; software implementation and hardware complexity, specifically the development of devices beyond those projected for the PMC facility. Both experiments require that the product samples at the end of the experiment be recovered, stored, and returned to earth. In experiment 16 this would require fixing a fractal. A method for doing this is not defined but would probably require crew interaction particularly since the fractals cannot be generated in earth gravity and the procedure may not be testable prior to flight. For experiment 14 a sample must be collected for each experiment run. The requirement for sample recovery is common to several experiments; this requirement may be difficult to implement during MTC and may be implemented only during PMC.

Table 42. Top-Level Timeline for Experiment 14 (Titan Atmosphere Aerosol Simulation)

Time (minutes)	0 - 20	20 - 50	50 - TBD	TBD - 1400	1400 - 1440	TBD
Experiment/ Function	Prepare chamber	Establish initial conditions	Initiate experiment	Particle growth phase	Stop experiment, collect samples	Clean chamber
Operation and/or Procedure	• Prepare gas mixture • Evacuate chamber • Admit gas mixture into chamber • Establish initial conditions	• Verify P, T • Measure background scattering • Check calibration	• Irradiate w/UV lamp • Monitor scattering • Imaging • Turn off lamp	• Maintain quiescent conditions • Monitor growth	• Scattering measurement off • Imaging off • collect particles • Remove sample & store	• Heat chamber (bake out) • Verify cleanliness
Measurement and Instrumentation Utilized	• Temperature • Pressure • Gas composition	• P, T • Diagnostics turn on (lamp, laser, detectors)	• P, T • Scattering (lamp, laser, detectors) • Imaging • UV source	• Cont. as before	• Storage container	• Lamp
Data Acquired	• Housekeeping (temp., press.) • Computer data acquisition	• Cont. as before	• Cont. as before • Imaging	• Cont. as before	• Same as before	• TBD
Power Utilization	• Electronics • Gas handling subsystem • Valves • P, T, sensors	• Electronics • Sensors • Lamp, laser, detector electronics • Thermal control	• Electronics • Sensors • CCD cameras & lighting • UV lamp	• Cont. as before • UV lamp off	• Cont. as before	• TBD
Crew Activity	• Initiate experiment	• TBD	• TBD	• TBD	• TBD	• TBD

Table 43 Top-Level Timeline for Experiment 16 (Study of Fractal Particles) (Continued)

Time (minutes)	0 - 30	30 - 45	45 - 105	105 - 120	120 - 360	360 - 1080[6,7]
Experiment/ Function	**A.** Establish chamber conditions	**B.** Introduce sample from crucible	**C.** Perform observations	**D.** End experiment	**E.** Repeat initial experiment[4]	**F.** Perform experiment variations[4,5]
Operation and/or Procedure	• Establish gas environment • Prepare materials in crucible • Make background optical measurements	• Establish temperature in crucible • Allow vapor to diffuse[1] into chamber and particles to nucleate • Establish initial conditions	• Measure intial scattering & extinction • Image fractals • Determine fractal structure[2] • Determine fractal strength[3]	• Obtain final measurements • Fix fractals[3] • Retrieve and store for return to earth • Status chamber, check instruments • Terminate operations	• Set up as in first column • Repeat experiment operations • Perform two more experiment runs	• Repeat steps A. & B. and induce growth • Admit O_2 after growth • Admit O_2 after nucleation and before step C • Repeat, but admit O_2 at step C • Ramp down temperature during and after fractal formed
Measurement and Instrumentation Utilized	• Temperature • Pressure • Cleanliness • Instrument check	• P, T • Diagnostics (scattering, extinction, imaging, light sources, detectors)	• Cont. as before • Perform ultrasonic measurements of strength	• Sample recovery apparatus • Storage container	• Same as before	• Same as step E
Data Acquired	• Housekeeping • Temperature • Pressure • Computer data acquisition	• Cont. as before • Scattering and extinction	• Cont. as before • Imaging data	• Cont. as before • Final chamber status	• Same as before	• Same as in B thru D
Power Utilization	• Sensors • Electronics • Valves	• Electronics • Sensors • Crucible • Diagnostics	• Electronics • Sensors • Optics • Imaging • Ultrasonic	• Cont. as before	• Same as before	• Same as A thru D
Crew Activity	• Initiate experiment	• TBD	• TBD	• TBD	• TBD	• TBD

[1] Diffusion and pressure driven flow.
[2] Quantity derived from above measurements.
[3] Optional, not always required.
[4] Steps E and F may be interchanged.
[5] Steps are typical of experiment variations.
[6] Time may vary depending on process
[7] This is one of many variations

Other operations involve chamber cleaning between experiments, which imposes a requirement to measure the level of cleanliness. During MTC this requires the development of a suitable test in which the cleanliness can be verified by ground analysis.

During MTC the sequence of operations will be to conduct one experiment repeatedly or to perform more than one or a few experiments. If more than one experiment is performed, all interfaces to the chamber must be validated prior to the start of an automated operation. Only experiments that are hardware compatible can be performed in the same sequence. The timeline of each experiment must be well-known prior to flight. The facility timeline will accommodate 90 to 180 days of experiment time, based on a preprogrammed sequence. The facility consumable resources will be adequate for these operations. All subsystems required for this time will be interfaced to the same chamber in the initial configuration.

There are requirements for the power and for the data timelines for the performance of each experiment. These timelines are experiment-specific and will be determined after final experiment selection.

5.3 Automation and AI

During MTC, the SSF will provide the most quiescent period of time while the shuttle is not docked. That time is ideal for those experiments that require a long-duration quiescent environment. The down side of the MTC time is that the facility will require extensive automation for operating within one experiment and for changing from one experiment to another. Various levels of GGSF operations have been defined and are listed in Table 44 in order of increased complexity.

Table 44. Automation Levels for the GGSF

LEVEL	OPERATION
1	Manual or remote control with a man-in-the-loop (on board or via down/up link)
2	Open-loop operations based on time sequencing or some trigger to start or stop certain operations
3	Simple closed-loop operations that utilizes simple sequencing or trigger to initiating certain operations, and utilize sensors with feed-back control for other activities
4	Operation based on a simple quantitative decision tree using a numerical algorithm or another logic device control and uses sensors, a data acquisition system, and digital control
5	Operations based on a complex set of conditions, qualitative and quantitative considerations, all of which can be anticipated in advance with experiment control that utilizes an expert system based on a heuristic inference engine, possibly in conjunction with a numerical model
6	Operations based upon a complex set of conditions not anticipated in advance but that can be extrapolated from previous experience with the control system that utilizes an adaptive neural network initially in a "supervised learning" mode that is "trained" to control the experiment

If necessary, the GGSF modular computer will allow for the implementation of AI and artificial neural network. Expert systems are developed these days at a cost no greater than that associated with conventional programming languages, and expert systems shells are available for all micro-

and mini-computer systems. Similarly, software emulations of neural networks are available at minimal cost for all mini- and micro computers. The control rationale and software will be developed in the laboratory and loaded into the computer.

Level 1 in Table 43 may not be available during MTC and may be better suitable for PMC. In general levels 2 through 4 will be appropriate for most experiments. The capability to upgrade the experiment control into levels 5 and 6 is provided by the GGSF modular computer.

5.4 Safety Considerations

The safety requirements of the GGSF will be governed by the SSF safety requirements. These are contained in NSTS 1700.7B Safety Policy and Requirements for Payloads Using the Space Transportation System (January 1989) plus Addendum 1 to this document, Space Station Freedom Payload Safety Requirements (draft only). The facility development will be required to adhere to the specifications of this document and will dictate in some instances the materials and methods of implementation that are to be used.

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APPENDICES

Appendix A

GGSF DATA BASE

5 November 1991

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	1B
Experiment Title	Low Velocity Collisions Between Fragile Aggregates
Contact:	Dr.S.J. Weidenschilling
Affiliation:	Planetary Science Institute 2421 E. 6th street Tucson AZ 85719-5234
Telephone:	602-881-0332

EXPERIMENT SUMMARY

Experiment Objectives

To simulate the earliest stages of the acccumulation of solid bodies in solar nebula. This is accomplished by determination of the velocity regimes for coagulation and disruption of aggregates and the determination of fragment size distributions in the latter regime. Aggregates are fragile and cannnot be manipulated in normal gravity. Stresses introduced by gravity would affect collisional outcomes.

Procedures

1) manufacture aggregates by compaction of prepared grains, or condense from the gas phase
2) after formation select and position two (or a small number)
3) measure: mass, density; observe motion
4) accelerate the particles under observation
5) observe and record impact on a prepared surface
6) clean chamber

Test Materials

Particles Aggregate silicate grains or silicate/ ice grains; porous,low-density, fractal-like in structure

Fluids CO2, CH4, NH3 (admixture) H2, or H2/He in chamber

Measurement Parameters

1) mean grain size, distribution
2) relative abundances of species
3) bulk density or filling factor (fractal structure)
4) aggregate velocities before and after impact
5) impact velocities and encounter geometry

Exp Duration (sec) Min 10 Max 100

Number of Experiments 100-1000

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	na
Dimension (cm) Min	10 (radius)
Dimension (cm) Max	meters
Volume (cm3)	4188 (calculated)
Chamber Material	not defined
View Ports	2
Measurement Angle Dependence	variable/ at least two orthogonal

ENVIRONMENT PARAMETERS

Gas Composition H2 or H2/He ; pure H2 probable

Gas Control	nr		
Gas Monitor	no		
Control Reqs	none		
Temperature (K)			
Max	500	**Min**	150 or less
Temperature Control	10		
Monitor and Accuracy	yes /tbd		
Gradient	nr		
Pressure (bar)			
Max	0.001	**Min**	0.000001
Pressure Monitor	measure to 2x		
Pressure Gradient	No		
Pressure Control	to 10x		
Humidity Control	nr	**Range**	

SAMPLE HANDLING

Sample preparation	Particles prepared on earth, maybe stored in vacuum. Aggregates prepared in situ by condensation from the gas phase, particularly the ice crystals.
Storage	perhaps under vacuum required
Constraints / other	1) vibration effect slight 2) other forces tbd
Introduction to Chamber	Not defined; separate the particles and accelerate one (mm/sec)
Material Composition	silicon, ice crystals
Concentration	2 aggregates min
Particle size	1μm
Particle Number Final	aggregates1mm-1cm (2)

In-Process Parameters

Levitation	none
Gases evolved	H2O vapor from ices
Env. Composition	nr
Experiment End Products	
Post Experiment Disposition	no particle recovery required; recover film

DIAGNOSTICS

Diagnostic Optical	high speed stereo camera (speed tbd)
Illumination source	high intensity light; white light
Wavelength range	white light
Nominal Diameter	up to 1mm
Resolution	1μm; larger for aggregates
Angle Measurement	na
Video Required	yes; frame rate tbd
Other Diagnostics	none

DATA INFORMATION (only if required)

Downlink	video
Real Time Readout	yes

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	none
On board Processing	nr
Voice Comm	probably

SAFETY CONCERNS

H2, silicate dust, volatiles (NH3, CH4)

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number 2B

Experiment Title Low Energy Grain Interaction/Solid Surface Tension

Contact: Dr. Reid Thompson

Affiliation: Space Sciences Bldg.
Cornell Univ.
Ithica, N.Y. 14853

Telephone: 607-255-8608

EXPERIMENT SUMMARY

Experiment Objectives

Small solid particles with appropriate crystal shapes are positioned near each other and their encounter is studied to determine the dynamics of the encounter. Particle emission is measured.
The experiment explores the physics of coalescence for solid, angular particles; slow processes which may result from activation-requiring processes and characterize third particle and photon impulse dissociation. Microgravity required to maintain an undisturbed environment.

Procedures

1) insert particles on a substrate into the chamber
2) lift particles from the substrate sequentially and position near each other (by laser pulse methods)
3) allow a controlled low-velocity encounter to occur
4) monitor the trajectory and subsequent readjustment of the particles
5) introduce third or additional particles

Test Materials

Particles silicate, ice, tholin, common crystal shapes

Fluids N2, H2, H2O

Measurement Parameters

1) position and motion of two particles
2) visible to uv light emission from particle interactions during and after contact

Exp Duration (sec) Min 600 Max 600

Number of Experiments 100's

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	tbd
Dimension (cm) Min	1.24 (calculated)
Dimension (cm) Max	
Volume (cm3)	1
Chamber Material	tbd
View Ports	2
Measurement Angle Dependence	two 180 deg apart; optimum tetrahedral

ENVIRONMENT PARAMETERS

Gas Composition N2, H2, H2O (to 1%)

Gas Control	no		
Gas Monitor	no		
Control Reqs			
Temperature (K)			
Max	300	Min	150
Temperature Control	5		
Monitor and Accuracy	1		
Gradient	no		
Pressure (bar)			
Max	1	Min	0.0001
Pressure Monitor	5%		
Pressure Gradient	none		
Pressure Control	no		
Humidity Control	tbd	Range	0-50%

SAMPLE HANDLING

Sample preparation	Brought from earth; except ice may be generated in situ
Storage	tbd
Constraints / other	minimize vibrations, and turbulence
Introduction to Chamber	particles inserted from tip of needle positioned using multple laser or acoustic positioning
Material Composition	individual particles
Concentration	2 up to several
Particle size	100 μm to 1mm, and down to 10 μm
Particle Number Final	2 to a few

In-Process Parameters

Levitation	yes, acoustic; light (laser) or radiometric positioning; 3D arrays
Gases evolved	none
Env. Composition	
Experiment End Products	
Post Experiment Disposition	no particle return

DIAGNOSTICS

Diagnostic Optical	image particles (high-speed video) fluorescence photometer or spectrometer computer particle recognition (planar control)
Illumination source	uv excitation source below 200 nm (H2 source)
Wavelength range	<200 nm
Nominal Diameter	100-1000 μm
Resolution	1 μm
Angle Measurement	180 deg
Video Required	yes to high resolution, 1μm
Other Diagnostics	determine the charge on the particle modify the charge on the particle

DATA INFORMATION (only if required)

Downlink	no
Real Time Readout	no

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	
On board Processing	yes, for positioning
Voice Comm	nr

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	3B
Experiment Title	Cloud Forming Experiment
Contact:	Dr.Jim Hudson
Affiliation:	Desert Research Institute P.O. Box 60220 Reno, Nevada 89506
Telephone:	702-677-3119

EXPERIMENT SUMMARY

Experiment Objectives

Form a water cloud in an expansion chamber using an aersol that is well characterized for its cloud forming ability; determine the rate at which droplets grow from an initially small size; determine how many droplets form & attempt to reduce the size by poisoning. Goals of the experiment include; determination of the condensation coefficient; measure the poly- dispersity of the cloud particle spectrum and incoproration of insoluble particles. Precise wall control and formation of the aerosol require microgravity.

Procedures

1) form and shape the aerosol (monodisperse or other)
2) characterize aerosol and transfer to chamber; establish known humidity
3) expand the aerosol and detect droplets; repeat compression and expansion with and without more nuclei
4) vary aerosol nuclei and droplets
5) mix in other air with or without aerosol.

Test Materials

Particles	water droplets; salt nuclei; soot ; other water insoluble particles; various salts
Fluids	water; air; cetyl alcohol

Measurement Parameters

droplet size with time
particle concentration
temperature; pressure; humidity

Exp Duration (sec)	**Min**	600	**Max**	86000
Number of Experiments	tbd			

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	tbd, 3 air ports
Dimension (cm) Min	28 (radius)
Dimension (cm) Max	na
Volume (cm3)	100,000
Chamber Material	
View Ports	2
Measurement Angle Dependence	tbd (assume yes)

ENVIRONMENT PARAMETERS

Gas Composition air with small amount of cetyl alcohol

Gas Control	0.1%(water)		
Gas Monitor	yes		
Control Reqs	yes		
Temperature (K)			
Max	303	**Min**	273
Temperature Control	30		
Monitor and Accuracy	0.001 (cool wall at rate at which the gas cools		
Gradient	none		
Pressure (bar)			
Max	1	**Min**	0.1
Pressure Monitor	yes		
Pressure Gradient	no		
Pressure Control	10-5		
Humidity Control	0.01%	**Range**	tbd

SAMPLE HANDLING

Sample preparation	aerosol formed in situ
Storage	nr
Constraints / other	tbd; temperature control 0.001 C
Introduction to Chamber	form cloud of droplets on nuclei, characterize the cloud and introduce into chamber
Material Composition	salts
Concentration	1-10000/ cm3
Particle size	nuclei .01-1 μm; drop 1-20 μm
Particle Number Final	tbd

<u>In-Process Parameters</u>

Levitation	none
Gases evolved	water vapor
Env. Composition	none
Experiment End Products	none
Post Experiment Disposition	tbd

DIAGNOSTICS

Diagnostic Optical	number and concentration
Illumination source	incandescent; multiwave laser
Wavelength range	
Nominal Diameter	0.1-100 μm
Resolution	tbd
Angle Measurement	tbd
Video Required	tbd
Other Diagnostics	

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	yes

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	
On board Processing	yes feedback control of wall temperature
Voice Comm	tbd

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	4
Experiment Title	Planetary Ring Dynamics
Contact:	Dr. Steve Squyres,
Affiliation:	Center For Radiophysics and Space Research Cornell University Ithica NY 14853
Telephone:	607-255 3508

EXPERIMENT SUMMARY

Experiment Objectives

To study planetary ring dyanamics by investigating the coefficient of restitiution in collision of planetary ring-like particles. Study the low velocity collisions of simulated planetary ring particles in a variety of configurations and environments. Measurements include impact parameter, particle composition sizes, surface texture, spin, temperature. Microgravity is required to maintain low impact velocities

Procedures

1) suspend one well characterized particle in a chamber; or a particle "target wall"
2) fire a second particle at the first, at low velocities
3) record the motions and trajectories of the particles before, during and after the impact
4) characterize the final particle

Test Materials

Particles "ice balls"; H2O ice, NH3 or CO2 ice

Fluids H2O; NH3; CO2; CH4

Measurement Parameters

particle velocity
collision dyanamics
particle rotation

Exp Duration (sec) Min 1 Max 10000

Number of Experiments 100+

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General

Dimension (cm) Min	10 radius
Dimension (cm) Max	none
Volume (cm3)	4188 (calculated)
Chamber Material	bake out
View Ports	3 orthogonal
Measurement Angle Dependence	yes, three orthogonal views

ENVIRONMENT PARAMETERS

Gas Composition na

Gas Control

Gas Monitor	no
Control Reqs	maintain vac.

Temperature (K)

Max	120	**Min**	60
Temperature Control	na		
Monitor and Accuracy	2		
Gradient	na		

Pressure (bar)

Max	0	**Min**	0 vac
Pressure Monitor	yes		
Pressure Gradient	maintain vac		
Pressure Control	tbd		

Humidity Control na **Range** na

SAMPLE HANDLING

Sample preparation	form ice balls or coated particles in chamber; or transport up
Storage	normal for the materials; maintian frozen if transported
Constraints / other	particles may require induced spin
Introduction to Chamber	one particle introduced into chamber and positioned; the second is required to be propelled accurately toward the first
Material Composition	ice
Concentration	single
Particle size	less than 3 cm
Particle Number Final	1 or several

In-Process Parameters

Levitation	maybe required initially for positioning
Gases evolved	H2O, NH3, CO2
Env. Composition	no control
Experiment End Products	none
Post Experiment Disposition	no return required; observe particle surface texture at site

DIAGNOSTICS

Diagnostic Optical	high speed imaging (camera; video; other) FOV of experiment volume
Illumination source	visible
Wavelength range	not crucial; visible
Nominal Diameter	cms
Resolution	tbd
Angle Measurement	yes 3 orthoginal
Video Required	high rate
Other Diagnostics	none

DATA INFORMATION (only if required)

Downlink	yes, high rate video
Real Time Readout	preferable

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	
On board Processing	tbd
Voice Comm	probably

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number 5B

Experiment Title Aggregation of Fine Particles in Planetary Atmospheres

Contact: Dr. John Marshall

Affiliation: Mail Stop 239-12
NASA Ames Research Center
Moffett Field CA 94035-1000

Telephone: 415-604-4983

EXPERIMENT SUMMARY

Experiment Objectives To determine the growth rates, sizes, composition and other properties of aggregates as a function of time, initial particle size, atmospheric composition, the mode of particle combination and other parameters. To use this data to relate to sedimentation rates, atmospheric residence and geographical residence.
The experiment is performed in microgravity to eliminate sedimentation and thus to optimize aggregate growth.

Procedures
1) introduce dust into the chamber
2) allow aggregation to occur
3) monitor the aggregation process

Test Materials

Particles finely comminuted lithological material (basalt, quartz, pyroclastic material, etc)

Fluids CO2;N2; air; H2O, inert gases

Measurement Parameters
size and size distribution of aggregates (0.1 μm to 1mm)
ambient conditions
wall deposition
aggregate shapes
extinction properties of the cloud

Exp Duration (sec) Min 7200 Max 7200

Number of Experiments ?

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	sphere
Dimension (cm) Min	20 diameter
Dimension (cm) Max	bigger is better
Volume (cm3)	4,189 (calculated)
Chamber Material	not critical
View Ports	3
Measurement Angle Dependence	photodetector 180 deg from source

ENVIRONMENT PARAMETERS

Gas Composition N2; earth atmosphere; CO2; H2O

Gas Control	nr
Gas Monitor	na
Control Reqs	na

Temperature (K)

Max	366	**Min**	221
Temperature Control	none		
Monitor and Accuracy	+/- 5% init (monitor across wall)		
Gradient			

Pressure (bar)

Max	1	**Min**	0.0001
Pressure Monitor	yes		
Pressure Gradient	no grad		
Pressure Control	+/- 10%		

Humidity Control to 2% nom **Range** 0

SAMPLE HANDLING

Sample preparation	up to 2 kg dust from earth; init 200 grams
Storage	normal
Constraints / other	cloud to remain clear of walls
Introduction to Chamber	introduce into the chamber through an air jet; define the level of isotropicity rather than achieving quiescence.
Material Composition	basalt, quartz, pyroclastic material
Concentration	10^8/cm3
Particle size	0.1 μm to 1mm
Particle Number Final	tbd

<u>In-Process Parameters</u>

Levitation	none
Gases evolved	none
Env. Composition	earth and mars atmosphere
Experiment End Products	particles and aggregates
Post Experiment Disposition	microscopic examination; if on-board then no return to earth

DIAGNOSTICS

Diagnostic Optical	- monochromatic source to measure extinction of cloud as f(λ) - size analyser (nephelometer) - microscope
Illumination source	2 orthogonal monochrom. sources short wavelength; laser?
Wavelength range	IR to UV
Nominal Diameter	0.1μm to 1mm
Resolution	tbd
Angle Measurement	yes
Video Required	high resolution, moderate speed
Other Diagnostics	none

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	nr

OTHER (comment only if known)

Gravity Level	
In Process tests	nr
On board Processing	no
Voice Comm	yes

SAFETY CONCERNS

dust

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	6B
Experiment Title	Condensation of Water on Carbonaceous Particles
Contact:	Dr. C. Fred Rogers
Affiliation:	Desert Research Institute P.O. Box 60220 Reno, NV 89506
Telephone:	702 -677-3178 / 510 486 5319

EXPERIMENT SUMMARY

Experiment Objectives

Study the time dependence of H2O on carbonaceous particles.Specifically examine the hypothesis that H2O condensation on insoluble, carbonaceous particles is initiated by an adsorption process that requires times of order 100-1000 seconds.
Micro gravity is needed to extend studies beyond 100 seconds

Procedures

1) generate particles by combustion of fuels
2) size classify and inject particles into a continuous flow diff (CDF) chamber
3) expose particles to H2O supersaturation; vary exposure time
4) pass exposed particles through an optical (or other) counter and measure

Test Materials

Particles	combustion products
Fluids	acetylene; liquid petroleum
Measurement Parameters	particles from 0.3 μm at n =1.33 forward scattering of particles

Exp Duration (sec)	**Min** 100	**Max**	10000
Number of Experiments	tbd		

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	requires continuous flow diffusion chamber
Dimension (cm) Min	20 x1 x30
Dimension (cm) Max	30 x2 x50 optimum
Volume (cm3)	600 cc - 3000 (calculated)
Chamber Material	particle free air
View Ports	tbd
Measurement Angle Dependence	none

ENVIRONMENT PARAMETERS

Gas Composition dry, particle free air may require chamber filter

Gas Control

Gas Monitor	no		
Control Reqs	particles		
Temperature (K)			
Max	303	**Min**	293
Temperature Control	gradient at CFD 1-10C		
Monitor and Accuracy	+/- 1 on plates		
Gradient			
Pressure (bar)			
Max	1	**Min**	0.5
Pressure Monitor	no		
Pressure Gradient	no		
Pressure Control	nr		
Humidity Control	5%	**Range**	dry at onset

SAMPLE HANDLING

Sample preparation	combust fuels burn fuels to prepare soot particles
Storage	fuels stored as hazardous materials
Constraints / other	maintain particle-free fuels
Introduction to Chamber	introduce the particles (from a second chamber ?) with injection slit and momentum diffuser
Material Composition	soot from combustion
Concentration	100-1000 cm3
Particle size	0.1μm to 1.0 μm
Particle Number Final	tbd

In-Process Parameters

Levitation	none
Gases evolved	none
Env. Composition	oxidizer in comb chamber; air in main chamber
Experiment End Products	
Post Experiment Disposition	collect sample on filter and return to earth downlink data, but not real time

DIAGNOSTICS

Diagnostic Optical	optical particle counter
Illumination source	tbd
Wavelength range	tbd
Nominal Diameter	0.3 to 1μm
Resolution	0.3 μm
Angle Measurement	tbd
Video Required	no
Other Diagnostics	none

DATA INFORMATION (only if required)

Downlink	no
Real Time Readout	no

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	inject known H2O vapor
On board Processing	possible
Voice Comm	no

SAFETY CONCERNS

stored fuels
smoke

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number 7AB

Experiment Title Optical Properties of Low Temperature Cloud Crystal

Contact: Dr. Shelley Pope Dr. Martin Tomasko

Affiliation: Mail Stop 239-1, NASA Ames Research Center, Moffett Field CA 94035-1000 — Lunar and Planetary Lab., University of Arizona, Tucson Az, 85721

Telephone: 415-604-6538 /602 621 6969

EXPERIMENT SUMMARY

Experiment Objectives Determine the crystal habits of ices (NH3, CH4, CO2 and others) grown at low temperatures (approximating the atmosphere of outer planets). Measure their single -scattering optical properties as a function of size and shape. Apply the results to planetary, particulary Jovian, atmosphere. At 1 g the growth times of the particles exceeds their fall times

Procedures

1) admit prepared gas mixture
2) lower temperature to achieve solidifcation
3) measure the scattering properties of resultant crystals
4) collect crystals and photograph
5) repeat experiment , varying conditions

Test Materials

Particles ices formed from gases and incorporated impurities (S, Ph, ...)

Fluids NH3, CH4, CO2

Measurement Parameters forward scattering over 180 deg function of wl. and polarization photograph grown crystals

Exp Duration (sec) Min 86000 Max

Number of Experiments tbd

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	accommodate a cylindrical window
Dimension (cm) Min	6 (dia) x 4
Dimension (cm) Max	none
Volume (cm3)	120 (min)
Chamber Material	no special reqs
View Ports	cylindrical window
Measurement Angle Dependence	180 deg variable

ENVIRONMENT PARAMETERS

Gas Composition NH3, CH4, CO2, N2, He, Ar (0 to 100 %)

Gas Control	5% init		
Gas Monitor	no		
Control Reqs	no		
Temperature (K)			
Max	300	**Min**	80
Temperature Control	0.5		
Monitor and Accuracy	0.1		
Gradient	yes to cont. relative saturation		
Pressure (bar)			
Max	3	**Min**	0.03
Pressure Monitor	10%		
Pressure Gradient	no		
Pressure Control	no		
Humidity Control	no	**Range**	water-free

SAMPLE HANDLING

Sample preparation	in situ
Storage	gases transported up
Constraints / other	vibration must be low enough to avoid wall collisions
Introduction to Chamber	produce ices in chamber from vapor
Material Composition	ices from particles
Concentration	4x10+7 to 40/cm3
Particle size	0.1 to 100 μm
Particle Number Final	tbd

<u>In-Process Parameters</u>

Levitation	none
Gases evolved	na
Env. Composition	no
Experiment End Products	
Post Experiment Disposition	arrange collection and the photography (imaging) of crystals grown during experiment

DIAGNOSTICS

Diagnostic Optical	measure particle scattering as a function of angle; line array detectors suggested camera or imager for post experiement
Illumination source	tungsten lamp with filters; 1000 watt and 100 watt
Wavelength range	0.3 to 1.0 micron variable
Nominal Diameter	.1 to 100 μm
Resolution	na
Angle Measurement	180 deg with variable angle
Video Required	yes
Other Diagnostics	none

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	if possible

OTHER (comment only if known)

Gravity Level	
In Process tests	controlled lowering of temperature to achieve crystal formation
On board Processing	tbd
Voice Comm	no

SAFETY CONCERNS

hazardous gases

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	8AB
Experiment Title	Ice Scavenging and Aggregation: Optical and Thermal IR Absorption and Scattering Properties
Contact:	Dr.John Hallett
Affiliation:	Desert Research Institiute P.O. Box 60220 Reno,NV 89506
Telephone:	702-677-3117/ 784-6780

EXPERIMENT SUMMARY

Experiment Objectives

To investigate the scavenging of aerosol and ice aggregation mechanics in the absence of convection and ventilation under controlled conditions. Water drops and ice crystals are grown and surrounded by a specific aerosol under different conditions including injecting with controlled velocities; growth and evaporation and obtaining diffusiophoric velocities. Absorption and scattering of the disperse ice particles are measured by either multiple or single path optics in the solar and thermal IR. This has direct application to the role of cirrus in global climate. Microgravity is required to control growth conditions and remove effects of convection. Experiments cannot be done in 1g for crystals greater than 10's of um as they will fall out too quickly.

Procedures

1) grow or inject seed crystals
2) nucleate the seed crystals and allow to grow, position if required
3) apply impulse (electric or acoustic field)
4) observe interactions
5) grow or evaporate crystal in aerosol
6) observe flux of aerosol in plane geometry thermal gradient
7) measure transmission/ scattering of solar/ thermal IR radiation as appropriate

Test Materials

Particles water drops, ice crystals, carbon aerosol

Fluids H2O, D2O, Ar, He

Measurement Parameters

particle size
aerosol scattering and aersol concentration
photography, imaging or video
microscopy
IR transmission FTIR

Exp Duration (sec) Min 3600+ Max 18000

Number of Experiments series

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	may require outside chamber to grow the crystal
Dimension (cm) Min	3 x 30
Dimension (cm) Max	1) 10 x 50 ; 2) 50 x 100
Volume (cm3)	2000 cc ; 500,000 cc
Chamber Material	normal
View Ports	5 ports
Measurement Angle Dependence	tbd

ENVIRONMENT PARAMETERS

Gas Composition Air, He, Ar, water vapor)

Gas Control	1% of press		
Gas Monitor	no		
Control Reqs			
Temperature (K)			
Max	293	**Min**	233
Temperature Control	0.1		
Monitor and Accuracy	0.1		
Gradient	20K /cm (diffusion chamber)		
Pressure (bar)			
Max	1 (10 atm)	**Min**	0.0001
Pressure Monitor	0.1%		
Pressure Gradient	none		
Pressure Control	1%		
Humidity Control	no	**Range**	saturation

SAMPLE HANDLING

Sample preparation	grow droplets or aerosols possibly in an outside chamber produce soot
Storage	normal
Constraints / other	electric field may be required for crystal orientation
Introduction to Chamber	samples are injected into the chamber or grown in situ crystals may be grown between two plates
Material Composition	water, ice, soot
Concentration	1/cc drop, crystal; 1000/cc aerosol
Particle size	0.1 μm aerosol; .5-1mm drops; 1-200 μm ice crystals
Particle Number Final	

In-Process Parameters

Levitation	yes, acoustic, for positioning of one crystal
Gases evolved	na
Env. Composition	drops plus aerosol
Experiment End Products	none
Post Experiment Disposition	retrieve ice crystals and evaporate for return for earth SEM analysis

DIAGNOSTICS

Diagnostic Optical	aerosol distribution particle size and position microscopy 10X to 50X FTIR
Illumination source	visible, for photography
Wavelength range	visible, IR
Nominal Diameter	micron to millimeter
Resolution	0.1μm
Angle Measurement	yes
Video Required	yes, high resolution, high speed possible
Other Diagnostics	

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	no

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	apply electric field or accoustic field to position
On board Processing	no
Voice Comm	yes

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	9B
Experiment Title	Synthesis of Tholins and Measurment of Their Optical Properties
Contact:	Dr. Bishun Khare
Affiliation:	Space Sciences Building Cornell University Ithaca NY 14853
Telephone:	607 255 3934

EXPERIMENT SUMMARY

Experiment Objectives

Perform low gravity experimentson the formation of Tholins. The conditions will simultate theTitan and then Uranus and Neptune atmospheres. A spectrometer operating between 0.2 and 2.5 μm will measure scattering for all phase angles. The constants n and k should be determined from the x-ray to 1 mm wavelength .
Microgravity will allow the particles to remain suspended with their own shape and will minimize the wall effect.

Procedures

1) establish gas mixture in flow chamber (initially simulate Titan)
2) apply rf discharge (50 watts) on the flowing gas
3) gas flows into plasma chamber containing prepared substrates
4) measure the scattering of the haze over the region 0.2 to 2.5 μm
5) continue measurements as the particles develop

Test Materials

Particles CH4 and N2 products from uv light source;RF; CsI, LiF, quartz, glass slides

Fluids CH4, N2

Measurement Parameters

Light scattering as a function of wavelength at several angles
initial intensity and the variation with time
measure particle size

Exp Duration (sec) Min 900 Max 1800

Number of Experiments tbd

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	
Dimension (cm) Min	15 x20-25 (cyl)
Dimension (cm) Max	no limit
Volume (cm3)	2000 -5000
Chamber Material	quartz (clean chamber)
View Ports	tbd
Measurement Angle Dependence	360 deg

ENVIRONMENT PARAMETERS

Gas Composition CH4 (10%), N2(90%)

Gas Control	3%		
Gas Monitor	no		
Control Reqs	yes		
Temperature (K)			
Max	tbd	**Min**	300
Temperature Control	tbd		
Monitor and Accuracy	tbd		
Gradient			
Pressure (bar)			
Max	0.002	**Min**	0.002
Pressure Monitor	yes		
Pressure Gradient	none		
Pressure Control	25%		
Humidity Control	nr	**Range**	nr

SAMPLE HANDLING

Sample preparation	premixed
Storage	as gas mixture and stable substrates
Constraints / other	form cloud (haze); RF discharge req'd
Introduction to Chamber	samples are formed from gases passed over an RF discharge substrates placed in chamber at experiment start
Material Composition	organics
Concentration	tbd
Particle size	1μm and smaller
Particle Number Final	tbd

In-Process Parameters

Levitation	none
Gases evolved	nr
Env. Composition	nr

Experiment End Products

Post Experiment Disposition	return the substrates with product to earth store data for return or downlink when convenient

DIAGNOSTICS

Diagnostic Optical	light scattering laser FTIR
Illumination source	spectormeter light source 0.2 to 2.5 μm source for FTIR 2-25 μm
Wavelength range	0.2 -2.5 μm
Nominal Diameter	up to micron
Resolution	tbd
Angle Measurement	as large as possible
Video Required	color video
Other Diagnostics	

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	no

OTHER (comment only if known)

Gravity Level	
In Process tests	none
On board Processing	yes; FTIR
Voice Comm	no

SAFETY CONCERNS

rf discharge
CH4

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number 10

Experiment Title Metallic Behavior of Aggregates

Contact: Dr. Denise Podoloski Traver

Affiliation: TBD

Telephone: tbd

EXPERIMENT SUMMARY

Experiment Objectives

Study the onset of metallic behavior of molecular aggregates as a function of 1) cluster size and composition (aggregate measurements) and 2) fractal dimensions (single particle measurements).
Low gravity is required to obtain longer gravitation times and because of the tenuous nature of the aggregates.

Procedures

1) expand vapor through a nozzle
2) initiate the condensation into aggregates - allow diffusion growth
3) measure the uv-visible spectrum and the scattering of the aggregates

Test Materials

Particles bimetallic -metallic vapors

Fluids

Measurement Parameters

UV visible spectrometer
light scattering (via laser at a single wavelength

Exp Duration (sec) Min tbd Max tbd

Number of Experiments tbd

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	tbd
Dimension (cm) Min	
Dimension (cm) Max	
Volume (cm3)	
Chamber Material	
View Ports	
Measurement Angle Dependence	

ENVIRONMENT PARAMETERS

Gas Composition tbd

Gas Control	tbd		
Gas Monitor	no		
Control Reqs			

Temperature (K)

Max	tbd	Min	tbd
Temperature Control	tbd		
Monitor and Accuracy	tbd		
Gradient			

Pressure (bar)

Max	tbd	Min	tbd
Pressure Monitor	tbd		
Pressure Gradient	tbd		
Pressure Control	tbd		

Humidity Control no Range nr

SAMPLE HANDLING

Sample preparation	at experiment initiation
Storage	normal
Constraints / other	tbd
Introduction to Chamber	form particles by the vaporization of the metals and recondensation difffusion growth of particles occurs during experiment
Material Composition	requires the selection of a single particle
Concentration	tbd
Particle size	1 μm -100 μm
Particle Number Final	nr

<u>In-Process Parameters</u>

Levitation	maybe for positioning
Gases evolved	tbd
Env. Composition	metal vapors
Experiment End Products	
Post Experiment Disposition	

DIAGNOSTICS

Diagnostic Optical	uv-visible spectrometer laser light scattering
Illumination source	white light source; laser
Wavelength range	0.2 -2.5 μ
Nominal Diameter	1-100 μm
Resolution	tbd
Angle Measurement	probably
Video Required	no
Other Diagnostics	none

DATA INFORMATION (only if required)

Downlink

Real Time Readout

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	establish conditions for aggregate growth

On board Processing

Voice Comm

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	11B
Experiment Title	Investigation of Organic Synthesis on Growing Particles
Contact:	Vern Oberbeck
Affiliation:	Mail Stop 239-12 NASA Ames Research Center Moffett Field CA 94035-1000
Telephone:	415-604-5496

EXPERIMENT SUMMARY

Experiment Objectives

Generate organic and silicate aerosols. Determine the effect of uv light on the aerosol composition. Monitor the particle growth and sample the aerosols to perform analysis of the bulk aerosol properties. Determine if the coalescence of particles could be an important process for chemical evolution.
Low gravity is required to maintain the reaction for the long period of time required to achieve the required aggregation.

Procedures

1) establish initial chamber conditions that simulate one condition in early earth atmosphere; turn on uv source
2) generate a multicomponent aerosol within the chamber
3) monitor the aerosol cloud size spectrum as a function of time
4) collect the cloud particles for return and analysis on earth.
5) repeat experiments varying parameters such as P,T, aerosol compositon and rate of adding material

Test Materials

Particles	silicates, amino acids,complex organics
Fluids	H2O, amino acids in solution
Measurement Parameters	aerosol size spectrometer HPLC (returned samples)

Exp Duration (sec)	**Min**	2400000	**Max**
Number of Experiments	tbd		

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	3 - 4	
Dimension (cm) Min	50	
Dimension (cm) Max	none	
Volume (cm3)	65449	- 523599 (calculated)
Chamber Material		
View Ports	3-4	
Measurement Angle Dependence	tbd (probable)	

ENVIRONMENT PARAMETERS

Gas Composition 90% CO2, 10% N2

Gas Control	5%		
Gas Monitor	tbd		
Control Reqs			
Temperature (K)			
Max	353	Min	203
Temperature Control	yes		
Monitor and Accuracy	+/- 5%		
Gradient	possible		
Pressure (bar)			
Max	1 (10 desirable)	Min	0.05r
Pressure Monitor	no		
Pressure Gradient	none		
Pressure Control	10% (4% at 10)		
Humidity Control	5%	Range	0 to 100%

SAMPLE HANDLING

Sample preparation	generate aerosols from aqueous solutions or silicate
Storage	solutions that are transported
Constraints / other	reduce turbulence with baffles; form quiescent cloud
Introduction to Chamber	introduce the material into the chambers in solution using gas driven aerosol generators and evaporate the solvent. May require illumination by xenon lamp
Material Composition	organics, silicates
Concentration	10+6 to 10+7/cm3
Particle size	0.1-0.2 µm/ monitor 0.12 -3.7 µm
Particle Number Final	2 µm particles 10+3 to 10+4/cc)

In-Process Parameters

Levitation	maybe required to stabilize the cloud
Gases evolved	tbd
Env. Composition	
Experiment End Products	wall material
Post Experiment Disposition	real-time analysis if possible; otherwise return to earth

DIAGNOSTICS

Diagnostic Optical	15 channel PMS aerosol spectrometer
Illumination source	200-300 nm source for monitoring
Wavelength range	200-300 nm
Nominal Diameter	0.12-3.7 µm
Resolution	0.12 µm
Angle Measurement	yes
Video Required	tbd
Other Diagnostics	HPLC

DATA INFORMATION (only if required)

Downlink	yes within 3-4 days
Real Time Readout	desired

OTHER (comment only if known)

Gravity Level	10-5
In Process tests	uv illumination of entire cloud xenon lamp
On board Processing	tbd
Voice Comm	no

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	12AB
Experiment Title	Crystallization of Protein Crystal Growth Inhibitors
Contact:	Dr. Jim Raymond
Affiliation:	Dept. of Biological Sciences, LSB 124 University of South Alabama Mobile AL 36688
Telephone:	205-460-7910/460-7357 fax

EXPERIMENT SUMMARY

Experiment Objectives	Produce macroscopic crystals, of antifreeze glycoprotein (AFGP) that are about 1mm in radius and suitable for x-ray diffraction. Determine the conformation of these molecules and clarify the mechanism of binding of protein crystal growth inhibitors to their crystal substrates. Microgravity will remove surface effects that inhibit growth and will enable better growth due to the removal of convection.
Procedures	1) chamber at 4 C, 80% rel humidity 2) suspend droplet of saturated protein solution, approx. 3 mm dia 3) maintain position for 12-24 hours until drop has dried to crystal or glass 4) remove sample
Test Materials	
Particles	
Fluids	solutions of protein in water
Measurement Parameters	possible light scattering

Exp Duration (sec)	**Min**	43000	**Max**	86000
Number of Experiments	10			

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	
Dimension (cm) Min	
Dimension (cm) Max	none
Volume (cm3)	10
Chamber Material	
View Ports	1
Measurement Angle Dependence	no

ENVIRONMENT PARAMETERS

Gas Composition air

Gas Control	no		
Gas Monitor	no		
Control Reqs	yes		
Temperature (K)			
Max	293	Min	277
Temperature Control	1		
Monitor and Accuracy	yes		
Gradient	no		
Pressure (bar)			
Max	1	Min	1
Pressure Monitor	no		
Pressure Gradient	no		
Pressure Control	no		
Humidity Control	1%	Range	80%

SAMPLE HANDLING

Sample preparation

Storage	solution possibly in syringe; frozen at 268K
Constraints / other	turbulence must be minimized
Introduction to Chamber	suspend droplet and maintian position
Material Composition	protein crystal
Concentration	1 (see note)
Particle size	1000 to 3000 μm
Particle Number Final	1

In-Process Parameters

Levitation	yes, accoustic for positioning (occasional)
Gases evolved	no
Env. Composition	no
Experiment End Products	protein crystal or glass
Post Experiment Disposition	return sample to earth for analysis

DIAGNOSTICS

Diagnostic Optical	tbd, possibly light scattering microscope
Illumination source	tbd not critical
Wavelength range	visible
Nominal Diameter	1 mm -3 mm
Resolution	0.05 mm
Angle Measurement	no
Video Required	tbd
Other Diagnostics	

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	tbd

OTHER (comment only if known)

Gravity Level	
In Process tests	maintain humidity
On board Processing	monitor status with microscope
Voice Comm	yes

SAFETY CONCERNS

tbd

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	13B
Experiment Title	Dipolar Grain Coagulation and Orientation
Contact:	Dr. Friedemann Freund
Affiliation:	Mail Stop 239-4 NASA Ames Research Center Moffett Field CA 94035-1000
Telephone:	415-604-5183

EXPERIMENT SUMMARY

Experiment Objectives

Understand the process of grain alignment in dust clouds and polarization of starlight and also the dimensionality of agglomeration of dust grains. A future goal is to understand the role of H2/CO/CO2 in cosmic dust and the single domain ferroelectric nature of minute silicate dust grains. This can lead to an understanding of the polarization of starlight.
The large filamentary aggregates expected are too fragile to study in 1 g.

Procedures

1) establish the chamber conditions
2) inject the dust (either created in situ or transported)
3) measure agglomeration in electric field
4) monitor grain size by measuring the polarization at various angles
5) monitor the filimentary orientation in an electric or a magnetic field
6) measure dielectric loss
7) characterize the grain aggregates (collect for ground or in situ analysis

Test Materials

Particles simple oxides (specifically Mg)

Fluids CO/CO2 /O2 in inert gases, H2O (only for in situ preparation)

Measurement Parameters

particle size, relative number and change with time
polarization measurements
laser doppler broadening
ref exp 7

Exp Duration (sec) **Min** 14000 (acitve) **Max** 18000

Number of Experiments several

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General		
Dimension (cm) Min	10	
Dimension (cm) Max	50	
Volume (cm3)	10	but 4188 min
Chamber Material		
View Ports	1 (?)	
Measurement Angle Dependence	180 deg	

ENVIRONMENT PARAMETERS

Gas Composition CO/CO2/O2 in He

Gas Control	0.5%		
Gas Monitor	no		
Control Reqs	tbd		
Temperature (K)			
Max	300	Min	77
Temperature Control	between ribbonand chamber		
Monitor and Accuracy	10 C		
Gradient	no		
Pressure (bar)			
Max	1	Min	0 low to vac
Pressure Monitor	tbd		
Pressure Gradient	no		
Pressure Control	no		
Humidity Control	no	Range	no

SAMPLE HANDLING

Sample preparation	burn the metals to oxides in a crucible; transfer to the chamber
Storage	normal
Constraints / other	prevent occlusion of particles at view ports
Introduction to Chamber	samples formed by burning (above) or brought from earth; cloud is contained in the chamber, two chamber experiment considered
Material Composition	simple oxides
Concentration	10+4 to 10+8 /cm3
Particle size	1 μm
Particle Number Final	10+6

<u>In-Process Parameters</u>

Levitation	tbd
Gases evolved	tbd
Env. Composition	tbd
Experiment End Products	
Post Experiment Disposition	return particles

DIAGNOSTICS

Diagnostic Optical	wide angle scattering, and determining polarization electric field polarization laser doppler broadening
Illumination source	Hg high pressure, filter wheel, laser, uv source
Wavelength range	0.2-2.5 μm
Nominal Diameter	100a to 1μm
Resolution	
Angle Measurement	yes, 90 deg
Video Required	tbd
Other Diagnostics	electric field (condenser plates)

DATA INFORMATION (only if required)

Downlink	no
Real Time Readout	no

OTHER (comment only if known)

Gravity Level	
In Process tests	
On board Processing	possible
Voice Comm	tbd

SAFETY CONCERNS

high temperature combustion
uv light, laser light

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	14AB	
Experiment Title	Titan Atmosphere Aerosol Simulation	
Contact:	Dr. Tom Scattergood	Dr. Chris Mckay
Affiliation:	Mail Stop 239-12 NASA Ames Research Center Moffett Field CA 94035-1000	Mail Stop 245-3
Telephone:	415- 604-6163 /415-604-5499	

EXPERIMENT SUMMARY

Experiment Objectives

1) Study growth of organic particles modeling the aerosols on Titan
2) Measure the optical properties (indices of refraction) of the particles
3) Study the chemical composition of the particles

Low gravity will allow the formation and the growth of particles in a containerless environment, entirely from the gas phase.

Procedures

1) prepare the chamber, evacuate, calibrate diagnostics and verify operational status
2) admit the appropriate gas mixture and establish a baseline
3) irradiate the mixture
4) measure the scattering properties during particle growth
5) retrieve particles for analysis

Test Materials

Particles organic materials made from CH4, other small hydrocarbons, N2, H2 (i.e.. tholins)

Fluids CH4, H2, N2, C2H2 , (C2H4)

Measurement Parameters

wide angle scattering of particles as they are formed
particle size, and shape
index of refraction
chemical compostion (post experiment)

Exp Duration (sec) Min 86400 Max 600000

Number of Experiments 1

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General

Dimension (cm) Min	10
Dimension (cm) Max	no limit
Volume (cm3)	4188 (calculated)
Chamber Material	normal
View Ports	3 to 4
Measurement Angle Dependence	wide angle measurerments

ENVIRONMENT PARAMETERS

Gas Composition CH4- 3-10%; N2 -90-97%; (H2 -0.2%) (possibly few% C2H2)

Gas Control	10%
Gas Monitor	no
Control Reqs	none

Temperature (K)

Max	300	**Min**	200
Temperature Control	no		
Monitor and Accuracy	10		
Gradient	no		

Pressure (bar)

Max	1	**Min**	0.001
Pressure Monitor	yes		
Pressure Gradient	no		
Pressure Control	none		

Humidity Control no **Range** dry

SAMPLE HANDLING

Sample preparation

Storage	gases transported up
Constraints / other	avoid any outgassing materials in chamber
Introduction to Chamber	particles are grown by uv radiation of gas mixtures during the experiment.
Material Composition	
Concentration	10+6 to 10+8/cc
Particle size	1 μm, aggregates to 10 μm
Particle Number Final	10+4

In-Process Parameters

Levitation	maybe
Gases evolved	none
Env. Composition	no
Experiment End Products	organic residue
Post Experiment Disposition	sample retained to return to earth do not retain gases

DIAGNOSTICS

Diagnostic Optical	uv light scattering laser light scattering (laser 600 nm- 2.5 μm)
Illumination source	uv lamp; laser
Wavelength range	?
Nominal Diameter	1 μm and less
Resolution	nr
Angle Measurement	yes
Video Required	desirable
Other Diagnostics	not on-board

DATA INFORMATION (only if required)

Downlink	possible
Real Time Readout	desired

OTHER (comment only if known)

Gravity Level	
In Process tests	tbd
On board Processing	
Voice Comm	tbd

SAFETY CONCERNS

fuels (CH4 ,C2H2)

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	15B
Experiment Title	Surface Condensation and Annealing of Chondritic Dust
Contact:	Dr. Frans Rietmeijer
Affiliation:	Dept of Geology University of New Mexico Albuquerque,NM 87131
Telephone:	505-277-2039

EXPERIMENT SUMMARY

Experiment Objectives

Simulate putative gas-dust reaction textures in extraterrestrial materials especially carbonaceous chondrite meteorites and cosmic dust. These materials give rise to new metal composites of cosmic importance. Obtain information on chemical composition and textures of these analogs. The experiement requires the availability of all particle surface area without interaction with chamber walls (i.e, containterless positioning).

Procedures

1) inject refractory oxide cores into a chamber
2) inject metal bearing gases as a function of decreased temperature
3) continue the process with new species as part of an annealing process
4) collect experimental products

Test Materials

Particles

HT refractory oxides; Al_2O_3, TiO_2, MgO both crystalline and amorphous; CaO, FeO, K_2O, Na_2O, NiO

Fluids

Measurement Parameters

optically measure the properties of the cloud

Exp Duration (sec)	**Min**	60000	**Max**	600000
Number of Experiments	35			

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	tbd
Dimension (cm) Min	25 dia
Dimension (cm) Max	none
Volume (cm3)	8181 min (calculated)
Chamber Material	tbd
View Ports	4
Measurement Angle Dependence	90 deg one det

ENVIRONMENT PARAMETERS

Gas Composition CaO, FeO, MnO, K2O, Na2O, NiO

Gas Control	5%
Gas Monitor	no
Control Reqs	no

Temperature (K)

Max	1200	Min	500
Temperature Control	25 ; 1 at the center		
Monitor and Accuracy	yes		
Gradient	no		

Pressure (bar)

Max	0.001	Min	0.000001
Pressure Monitor	yes		
Pressure Gradient	no		
Pressure Control	no		

Humidity Control yes Range dry

SAMPLE HANDLING

Sample preparation	particles transported up
Storage	normal
Constraints / other	particles cannot strike walls
Introduction to Chamber	low velocity injection or release ultrasonically from a retractable rod.
Material Composition	refractory oxides
Concentration	10+6 to 10+8/cm3
Particle size	10-50 nm
Particle Number Final	10+6

In-Process Parameters

Levitation	no
Gases evolved	no
Env. Composition	no
Experiment End Products	tbd
Post Experiment Disposition	electro micro beam analysis

DIAGNOSTICS

Diagnostic Optical	position of the particle cloud and particle size transmitted light and IR light
Illumination source	visible light; IR for particle sizing
Wavelength range	visible and IR
Nominal Diameter	10 -100 nm
Resolution	10 nm
Angle Measurement	tbd
Video Required	yes
Other Diagnostics	not on-board

DATA INFORMATION (only if required)

Downlink	no
Real Time Readout	no

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	
On board Processing	control only
Voice Comm	no

SAFETY CONCERNS

high temperature
metal organics

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	16B	
Experiment Title	Studies of Fractal Particles	
Contact:	Dr. Joe Nuth *	Dr. John Stephens
Affiliation:	Code 691 NASA Goddard Space Flt Ctr Greenbelt Md 20771	CHM-2, Mail Stop C-348 Los Alamos National Lab Los Alamos NM 87545
Telephone:	301-286-9467 / 505-667-7363	

EXPERIMENT SUMMARY

Experiment Objectives

Understanding the radiative and dynamic characteristics of a variety of fractal materials which may have astrophysical significance.
Fractal particles of large size can be grown in microgravity but not in 1 g. The growth time scale is larger in low gravity permitting longer growth times and particle growth to one centimeter or larger

Procedures

1) establish the initial chamber conditions
2) introduce a silicate or metal vapor from a crucible evaporator
3) perform observations on the growing aggregate
4) repeat for three runs
5) repeat steps 1 to 3 but admit O2 after growth and before step 3)
6) repeat 5) but admit O2 immediately after nucleation
7) repeat above with different vapors

Test Materials

Particles metal, simple silicates, ice-coated metals and simple silicates(SiO. Fe, Mg, Zn, Bi)

Fluids Ar, H2, O2, Xe, CH4, H2O, CO, CO2, NH3

Measurement Parameters

coagulation coeffiecient
scattering and extinction efficiencies of aggregates
measurment of the fractal structure and shear strength
collection of samples

Exp Duration (sec) **Min** 3600 **Max** 100000

Number of Experiments 9 to 45

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	
Dimension (cm) Min	10
Dimension (cm) Max	none
Volume (cm3)	4188 (calculated)
Chamber Material	no pre-existing particles in vapor
View Ports	3
Measurement Angle Dependence	detectors at 90 and 180 deg to light (several angles)

ENVIRONMENT PARAMETERS note high temp at crucible (1500) cham

Gas Composition H2 (1%), Ar (99%), O2 trace (init); ice-coating requires various combinations of Xe (1-2 Atm); H2O, CH4, CO, CO2, NH3 (10-20 torr)

Gas Control	5%		
Gas Monitor	yes		
Control Reqs	yes		
Temperature (K)			
Max	300 (see note)	**Min**	4
Temperature Control	5% high 50% low		
Monitor and Accuracy	.5		
Gradient	yes		
Pressure (bar)			
Max	1	**Min**	1
Pressure Monitor	yes		
Pressure Gradient	none		
Pressure Control	10%		
Humidity Control	no	**Range**	0

SAMPLE HANDLING

Sample preparation	cloud prepared in a crucible at 1500-2000 K, expand into chamber
Storage	normal
Constraints / other	no disturbance of fractals during growth
Introduction to Chamber	vaporization from crucible in the chamber
Material Composition	
Concentration	10+8 to 10+10/ cc
Particle size	10 nm
Particle Number Final	1 after aggregation

In-Process Parameters

Levitation	none
Gases evolved	no
Env. Composition	yes
Experiment End Products	fractals , fragile materials
Post Experiment Disposition	return samples to earth and perform SEM analysis; fix samples in matrix

DIAGNOSTICS

Diagnostic Optical	scattering/ extinction measurements; optical properties of fractals multiple wavelength; multiple angles
Illumination source	Xe arc lamp, laser(s), H2 lamp
Wavelength range	0.17 to 30 μm (.3 to .7 prime)
Nominal Diameter	20 nm to 1 cm
Resolution	video
Angle Measurement	90 and 180 deg to lamp
Video Required	yes, high resolution
Other Diagnostics	fractal shear strength using ultrasonic techniques

DATA INFORMATION (only if required)

Downlink	video
Real Time Readout	yes (not necessary)

OTHER (comment only if known)

Gravity Level	10-5
In Process tests	add gases at specified times; activate acoustics at specified times
On board Processing	nr
Voice Comm	yes

SAFETY CONCERNS

high temperature at crucible, but ambient at the walls

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	17AB	
Experiment Title	Optical Properties of Particles and Clusters	
Contact:	Dr.Lou Allamandola *	Dr. John Goebel
Affiliation:	Mail Stop 245-6 NASA Ames Research Center Moffett Field CA 94035-1000	Mail Stop 244-10
Telephone:	415-604-6890 / 415-604-3188	

EXPERIMENT SUMMARY

Experiment Objectives

Measure radiative properties of clusters of molecules and microparticles and understand how radiative energy is converted from the UV to the IR in various environments
Two goals are to measure this for clusters (A) and for single particles (B)
Microgravity allows sufficient time for molecular clusters to form and, in the case of a single particle, time to accumulate sufficient signal and measure free species.

Procedures

1) prepare chamber
2) generate clusters or particles
3) position particles in the chamber
4) monitor the emission continuously
5) warm or electonically excite the particles with ultraviolet or visible radiation while continuing the monitoring
6) vary power level or the degree of excitation

Test Materials

Particles clusters of polycyclic hydrocarbons; carbon grains, minerals

Fluids inert gases ,ice parents ,gases (eg H2O, CO, CH3OH, NH3,etc)

Measurement Parameters

excitation of particles
heat loss (red near IR and IR) spectrum from particles

Exp Duration (sec) Min tbd Max tbd

Number of Experiments tbd

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	
Dimension (cm) Min	20
Dimension (cm) Max	none
Volume (cm3)	33510 (calculated)
Chamber Material	
View Ports	4-6
Measurement Angle Dependence	variable angles

ENVIRONMENT PARAMETERS

Gas Composition inert gases, eventually gases such as H2O, CH3OH, NH3, C3H8, etc

Gas Control	nr		
Gas Monitor	no		
Control Reqs	nr		
Temperature (K)			
Max	300	**Min**	10
Temperature Control	walls cooled to reduce background		
Monitor and Accuracy	2 -5		
Gradient	no		
Pressure (bar)			
Max	0.00000001	**Min**	0.0000000001
Pressure Monitor	yes		
Pressure Gradient	no		
Pressure Control	factor of 2		
Humidity Control	nr	**Range**	dry; no water

SAMPLE HANDLING

Sample preparation	possibly in situ
Storage	if possible transport a single particle
Constraints / other	maintain the position of the cloud or of the single particle
Introduction to Chamber	If possible particles are injected by a jet into the chamber and single particle could be suspended; particles may be prepared by heating from a solid or ablating a solid
Material Composition	organics or carbon, carbon grains
Concentration	single up to10+10 cm3
Particle size	5-100A (cluster) .05-1μm part
Particle Number Final	tbd

<u>In-Process Parameters</u>

Levitation	yes
Gases evolved	no (perhaps if ices are used)
Env. Composition	na
Experiment End Products	none
Post Experiment Disposition	if possible bring particles back to earth

DIAGNOSTICS

Diagnostic Optical	laser excitation; measure spectra; signal vs frequency (light source)
Illumination source	broad band laser or continuous light source tbd
Wavelength range	100 nm to 10 cm-1
Nominal Diameter	5 - 100A
Resolution	1-5A near IR; 1-10 cm-1 IR/far IR
Angle Measurement	detector variable with respect to excitation source
Video Required	no but tbd
Other Diagnostics	mass spectrometer for ices (secondary requirement)

DATA INFORMATION (only if required)

Downlink if possible

Real Time Readout yes

OTHER (comment only if known)

Gravity Level

In Process tests

On board Processing no

Voice Comm

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number 18B

Experiment Title Effect of Convection on Particle Deposition and Coagulation

Contact: W.K Rhim

Affiliation: JPL /Calif. Inst Tech MS 183-401
4800 Oak Grove Drive
Pasadena CA, 91109-8099

Telephone: 818 -354- 2925

EXPERIMENT SUMMARY

Experiment Objectives

Study the effect of convection on deposition and coagulation of micron and larger sized particles
The experiement requires well-defined convection and the absence of gravity induced convection. Gravitationally induced depositon is avoided.

Procedures

1) establish initial conditons
2) generate aerosol
3) monitor the size spectrum of the aerosol through the approach to steady state and beyond while the aersol is added at a constant rate
4) remove generator and monitor the transient decay
5) repeat experiment varying the particles and/ or concentrations

Test Materials

Particles liquid and solid microspheres; various materials

Fluids

Measurement Parameters

aerosol size spectrum
temperature, pressure , humidity

Exp Duration (sec) Min 3600 Max n x3600

Number of Experiments 100

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	
Dimension (cm) Min	5 x5 x5
Dimension (cm) Max	15 x 15 x15
Volume (cm3)	125 - 3375 (calculated)
Chamber Material	not important
View Ports	3-4
Measurement Angle Dependence	yes

ENVIRONMENT PARAMETERS

Gas Composition air

Gas Control	no		
Gas Monitor	no		
Control Reqs	nr		
Temperature (K)			
Max	373	Min	293
Temperature Control	2		
Monitor and Accuracy	1		
Gradient	no		
Pressure (bar)			
Max	1	Min	1
Pressure Monitor	1%		
Pressure Gradient	no		
Pressure Control	2 %		
Humidity Control	yes	Range	0 to 100%

SAMPLE HANDLING

Sample preparation	particles brought from earth aerososl formed in situ
Storage	normal
Constraints / other	
Introduction to Chamber	produce the cloud by standard microsphere techniques (vibrating orfice aerosol generator (VOAG)); particles are injected from the VOAG jet into the chamber
Material Composition	various solids or water
Concentration	10 to 10+5/cc
Particle size	1 to 20 μm
Particle Number Final	up to 10+5

In-Process Parameters

Levitation	none
Gases evolved	none
Env. Composition	not required
Experiment End Products	none
Post Experiment Disposition	none

DIAGNOSTICS

Diagnostic Optical	optical counter (various ranges) scattering particle counting
Illumination source	visible; laser
Wavelength range	visible
Nominal Diameter	1-20 μm
Resolution	tbd
Angle Measurement	yes
Video Required	yes
Other Diagnostics	

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	downlink data between runs

OTHER (comment only if known)

Gravity Level	
In Process tests	maintain flow rate of injection by feedback mechanism
On board Processing	feedback loops to control the aerosol flow
Voice Comm	no

SAFETY CONCERNS

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	19
Experiment Title	Growth and Reproduction of Microorganisms in a Nutrient Aerosol
Contact:	Dr. Steven Welch
Affiliation:	Complex Systems Research 7079 Redwing Place Niwot , CO 80503
Telephone:	303-666-4137

EXPERIMENT SUMMARY

Experiment Objectives

The primary goal is to determine if a microorganism can reproduce in an aerosol. This goal has implications for the possibility of life elsewhere in the solar system. A secondary goal is tthe development of microbiological techniques that can be performed in microgravity. These techniques will have application to long duration space flights.
Low gravity is required to keep droplets with sufficient nutrient suspended for a time long enoug to monitor growth.

Procedures

1) establish the culture of selected microorganism in a nutrient solution
2) establish chamber conditions and introduce solution into the chamber in aerosol form (may require initial sterilizatiion of the chamber)
3) after aerosol is established perform initial particle and culture count
4) maintian chamber conditions for several days with periodic monitoring of the particles and the microorganism count
5) collect the aerosol and analysis for metabolism of nutrients and growth

Test Materials

Particles	microorganisms in aqueous solution
Fluids	water, air , formaldehyde or ethylene oxide for sterilization; CO2

Measurement Parameters

scattering of the aerosol to measure concentration and size; without disturbing the microorganisms
periodic sampling of the aerosol to determine the microorgansim concentration

Exp Duration (sec) Min tbd Max 86000000

Number of Experiments tbd

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	requires a sampling port
Dimension (cm) Min	
Dimension (cm) Max	
Volume (cm3)	1000000 - 10000000
Chamber Material	sterilized
View Ports	1-2
Measurement Angle Dependence	probably

ENVIRONMENT PARAMETERS sterilize chamber

Gas Composition air (80% N2, 20% O2, .03% CO2) water saturated

Gas Control	tbd		
Gas Monitor	yes CO2		
Control Reqs	CO2 only		
Temperature (K)			
Max	313	**Min**	263
Temperature Control	no		
Monitor and Accuracy	2 C		
Gradient	tbd		
Pressure (bar)			
Max	1	**Min**	<1
Pressure Monitor	yes		
Pressure Gradient	no		
Pressure Control	tbd		
Humidity Control	no	**Range**	100%

SAMPLE HANDLING

Sample preparation	prepare solution of microbes in nutrient
Storage	microbes, water and nutrient solution maintained sterile
Constraints / other	maintain culture
Introduction to Chamber	introduce the active solution into the aerosol generator and disperseinto the chamber so as to maintain the culture; injection occurs through a nebulizer
Material Composition	microorganism in water
Concentration	300/cm3 (3x10-5g/cc)
Particle size	>25 μm (25-50 μm)
Particle Number Final	tbd

<u>In-Process Parameters</u>

Levitation	maybe-perhaps intermittant
Gases evolved	none that change composition
Env. Composition	yes, CO2
Experiment End Products	
Post Experiment Disposition	measure nutrient changes due to metabolism (could be at earth); final concentration of organisms determined; chamber may req. sterilization

DIAGNOSTICS

Diagnostic Optical	nepholometer for scattering measurements spectrophotometer automated MPN or other microbial count method
Illumination source	intensity and wavelength such that organisms are not disturbed grow lamp may be required in later experiements
Wavelength range	visible
Nominal Diameter	25-50 μm
Resolution	10%
Angle Measurement	180 deg
Video Required	tbd
Other Diagnostics	organism count mechansim

DATA INFORMATION (only if required)

Downlink	tbd
Real Time Readout	yes, of organsim growth parameters to monitor experiment health

OTHER (comment only if known)

Gravity Level	tbd
In Process tests	periodic removal of portion of the aerosol for analysis
On board Processing	yes, to determine the organism level
Voice Comm	yes

SAFETY CONCERNS

microorganisms present

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number	20
Experiment Title	Long-Term Survival of Human Microbiota in and on Aerosols
Contact:	Dr. Steven Welch
Affiliation:	Complex Systems Research 7079 Redwing Place Niwot , CO 80503
Telephone:	303-666-4137

EXPERIMENT SUMMARY

Experiment Objectives

Primary goal is to determine whether human micobiota can survive for long periods of times in an aerosol in microgravity. A secondary goal is the development of microbiological techniques performable in microgravity.
The microgravity environment is essential since the microbiota will settle out on earth whereas in space they may persist for an extended time (this experiment is similar to exp 19)

Procedures

1) prepare a culture of the selected organism in a water-based buffer solution
2) prepare chamber including sterilization
3) introduce the solution into the chamber in aerosol form
4) monitor initially to establish initial conditions and then periodically
5) collect the aerosol at end of experiment
6) sterilize the chamber

Test Materials

Particles	microorganisms in an aerosol
Fluids	air components, perhaps formaldehyde and ethylene oxide
Measurement Parameters	aerosol particle number and size microbe number per particle with experiment time

Exp Duration (sec)	**Min**	6000000	**Max**	12000000
Number of Experiments	tbd			

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General	must be sterilizable
Dimension (cm) Min	
Dimension (cm) Max	
Volume (cm3)	1000000 - 10000000
Chamber Material	sterilized
View Ports	1-2
Measurement Angle Dependence	probable

ENVIRONMENT PARAMETERS

Gas Composition air

Gas Control	tbd		
Gas Monitor	CO2		
Control Reqs	CO2 only		
Temperature (K)			
Max	303	Min	283
Temperature Control	tbd		
Monitor and Accuracy	2 C		
Gradient	no but maintian constant		
Pressure (bar)			
Max	1	Min	<1
Pressure Monitor	yes		
Pressure Gradient	no		
Pressure Control	tbd		
Humidity Control	no	Range	100%

SAMPLE HANDLING

Sample preparation	prepare microbes in a nutrient solution
Storage	microbes and nutrient controlled
Constraints / other	maintain chamber integrity and sterility
Introduction to Chamber	microbe solution is introduced into an atomizer and then into the chamber
Material Composition	water-based aerosol containing
Concentration	300 /cm3
Particle size	25-50 µm
Particle Number Final	tbd

<u>In-Process Parameters</u>

Levitation	tbd
Gases evolved	
Env. Composition	CO2
Experiment End Products	tbd
Post Experiment Disposition	measurement of the nutrient metabolized and the final microbe population this can be done on-board

DIAGNOSTICS

Diagnostic Optical	nepholometer to measure aerosol number and size spectrophotometer for optical density
Illumination source	visible only, no UV or IR which could disturb the culture
Wavelength range	visible only
Nominal Diameter	25-50 µm
Resolution	10%
Angle Measurement	yes,
Video Required	tbd
Other Diagnostics	microbe count

DATA INFORMATION (only if required)

Downlink	yes
Real Time Readout	yes, both on board and down link

OTHER (comment only if known)

Gravity Level	
In Process tests	periodically remove sample or otherwise measure the microbe level
On board Processing	yes to monitor microbe counts
Voice Comm	yes

SAFETY CONCERNS

microbes
toxic sterilizer gases

GAS GRAINS EXPERIMENT INFORMATION SURVEY

GENERAL

Experiment Number 21B

Experiment Title Study of Smoke Agglomerates

Contact: Dr. George W. Mulholland

Affiliation: Penn State Univ
Center for Particle Science /109 Steidle Bldg.
State College PA 16802-5005

Telephone: 814-865-8101

EXPERIMENT SUMMARY

Experiment Objectives To understand the optical and dynamic characteristics of large smoke agglomerates
Micro-gravity will allow the growth of larger agglomerates that would settle out at 1 g.

Procedures
1) prepare chamber
2) generate smoke agglomerates using a laminar flame
3) fill transmissio -cell reciprocal-nephelometer with smoke agglomerates
4) perform measurements of light extinction, total scattering, and angle dependent scattering; at preset times sample smoke for subsequent electron microscopy and for real time number and mass concentration measurements

Test Materials

Particles smokes

Fluids acetylene; air

Measurement Parameters particle size; particle number
dyanamics of the smoke agglomerates
particle structure

Exp Duration (sec) Min 86000 Max 600000

Number of Experiments tbd

CHAMBER (geometrical properties, only critical properties need be defined)

Shape/General

Dimension (cm) Min	10 dia; 100 lg
Dimension (cm) Max	no
Volume (cm3)	7853
Chamber Material	no
View Ports	tbd (2)
Measurement Angle Dependence	5 to 160 deg

ENVIRONMENT PARAMETERS

Gas Composition air

Gas Control	1%		
Gas Monitor	no		
Control Reqs	yes		
Temperature (K)			
Max	298	**Min**	298
Temperature Control	1		
Monitor and Accuracy	1		
Gradient	no		
Pressure (bar)			
Max	1	**Min**	1
Pressure Monitor	1%		
Pressure Gradient	no		
Pressure Control	2%		
Humidity Control	no	**Range**	no more than 70%

SAMPLE HANDLING

Sample preparation	controlled combustion in laminar flame
Storage	fuel control storage
Constraints / other	a thermophoretic collector is used
Introduction to Chamber	smoke is formed and transported to nephelometer cell through a port in the chamber wall
Material Composition	carbon smoke
Concentration	10+6 to 10+8
Particle size	30 nm; agglomerates .1-1 μm
Particle Number Final	tbd

In-Process Parameters

Levitation	none
Gases evolved	combustion products
Env. Composition	no
Experiment End Products	tbd
Post Experiment Disposition	tbd

DIAGNOSTICS

Diagnostic Optical	light extinction, total scattering, angle dependent scattering (see supplied diagram)
Illumination source	He-Ne laser
Wavelength range	632.8 nm
Nominal Diameter	30 nm-100 μm
Resolution	100 nm
Angle Measurement	yes
Video Required	no
Other Diagnostics	sample removed for SEM etc TEOM Concentration nuclear counter

DATA INFORMATION (only if required)

Downlink

Real Time Readout yes

OTHER (comment only if known)

Gravity Level

In Process tests particles are manipulated through a thermophoretic collection grid

On board Processing yes

Voice Comm no

SAFETY CONCERNS

hydrocarbon fuel
combustion process
laser; beta source

Appendix B
Chamber Cooling: First Order Approximation

A simplified analysis of the chamber cooling

The following is a simplified analysis of the chamber cooling and is not presented as a precise thermal model or analysis. Its intent is to reveal the physics, the parameters of importance, their influence, and the combination of parameters, which control the chamber cooling behavior. The analysis applies both to the cooling and heating of a chamber, although we refer to cooling only throughout this appendix. It also presents a "back-of-the-envelope" approach for sizing the chamber (based on thermal considerations), for estimating cooling time and the maximum cooling with a given cryocooler. The analysis makes it easy to understand the importance of various parameters and their influence without using computerized thermal models.

We begin with a relatively simple case and progress to more complex ones. The sequence becomes: (1) describe a simplified model without radiation heat transfer; (2) work the steady-state solution and transient equation; (3) evaluate the parameters such as characteristic cooling time and maximum ΔT; (4) introduce radiation and study its influence on the solution; and (5) assess the effects of radiation shielding and how it modifies the parameters. The model at this point becomes too complex for a closed-form analytical solution; thus a numerical solution is required. Yet, a few simplifications can be introduced which allow the understanding of the physics without resorting to a complete numerical analysis.

The model

The simplified heat transfer model. without radiative transfer, assumes that the chamber is made of a double-walled structure and that heat is conducted from the outer to the inner wall (or vice versa for a heated chamber). Heat is removed by a cryocooler directly from the inner wall and no temperature gradients are assumed to exist in the inner wall.

$$-mc_p\frac{dT}{dt} = q_o(T - T_z) - \frac{kA}{d}(T_a - T) \qquad (1)$$

Equation (1) describes the rate of cooling of the inner chamber mass, m, due to heat removal by the cryocooler and the competing effect of conductive heat transfer from the outer chamber wall. The following nomenclature is used: The cryocooler's heat rejection power is assumed to be linear with the temperature (i.e., $q = q_o(T - T_z)$) and it is zero at T_Z (this linearity is not a bad approximation over a narrow temperature range, but we use it here over the complete range from 300 K to T_Z which is, say, 40 K). The conductive heat load is due to the outer chamber wall temperature T_a (e.g., ambient, or 300 K), and k is the thermal conductivity of the material filling the gap of thickness d between the two chamber shells. The surface area of the chamber, A, is that of a sphere with an equivalent diameter, D. The inner chamber temperature, T, is the variable being solved for. Free convection is not considered in this analysis since the Grashof number ($Gr = \rho^2 g l^2 \beta \Delta T/\mu^2$) is proportional to the g level which is about 5 orders of magnitude smaller in space than on earth (the terms in the definitions of Gr are in order of appearance, density, gravitational acceleration, characteristic length, temperature coefficient of thermal expansion, temperature difference, absolute viscosity). In a detailed analysis, the order of magnitude of the free convection effect should be considered.

We briefly look at the steady-state solution, i.e., after long enough time when the system has reached the lowest temperature possible. This, obviously, happens when the heat rejection power of the cryocooler is equal to the conductive heat load. The L.H.S. of Eq. (1) can be ignored, therefore, and the solution is obtained by equating the R.H.S. to zero and solving for T. The solution, quite simply, is:

$$T = \frac{q_o T_z + \frac{kA}{d} T_a}{q_o + \frac{kA}{d}} = T_f \tag{2}$$

We define this value as T_f, the final, steady-state temperature. Later we will assess the magnitude of the variables in this equation to get a better feel for the final temperature. Going back to Eq (1), after some rearrangement of the parameters, and rewriting as:

$$\frac{dT}{dt} + \frac{T}{\tau} - \frac{T_f}{\tau} = 0 \tag{3}$$

This much simplified equation is derived by lumping together various groups of parameters. This grouping is not arbitrary, though, and as we show, serves a very useful purpose. The groups are as follows:

$$\tau = \frac{mC_p}{q_o + \frac{kA}{d}} \tag{4}$$

Here τ has units of time and, as shown later, serves as an important characteristic time to describe the chamber cooling period.

$$T_f = \frac{q_o T_z + \frac{kA}{d} T_a}{q_o + \frac{kA}{d}} \tag{2}$$

T_f, as we have seen earlier, is the steady-state solution, or the lowest temperature the system would reach. The solution to the transient equation is obtained by inspecting equation (3). We know that after a very long time the solution must converge to the steady-state solution, T_f. We also know that for a first-order differential equation the solution will be exponential. One can guess (or go through the rigorous procedure) the solution to be:

$$\boxed{T_a - T = (T_a - T_f) \cdot (1 - e^{-t/\tau})} \tag{5}$$

If we define $\Delta T_{max} = T_a - T_f$ and $\Delta T = T_a - T$, then the solution can be neatly written as:

$$\frac{\Delta T}{\Delta T_{max}} = 1 - e^{-t/\tau} \tag{6}$$

where

$$\Delta T_{max} = \frac{q_o (T_a - T_Z)}{q_o + \frac{kA}{d}} \tag{7}$$

Analysis of results

Before going to the next level of complexity, we evaluate some of the parameters involved. These parameters provide and excellent insight into the chamber cooling characteristics and some design considerations. We assess two sizes of spherical chambers: a 60 cm and a 20 cm (diameter). We further assume that each has a double-walled construction, and look at the selection of possible fill substance for the gap between the walls. For each of these cases we than calculate the ΔT_{max}, T_f, and τ . The materials for use in the gap are N_2 (least expensive), Xe gas (noble gas with the lowest thermal conductivity), and MLI in vacuum (multilayer insulation, serves basically as thermal radiation heat shield, but due to its construction it has some finite thermal conductivity). At this point we ignore the radiation and treat the MLI strictly as an insulation. In a sense one could assume no insulating material (only a vacuum-jacketed double-wall construction) but this serves as a good example to the impact of the thermal conductivity. We further assume that the inner chamber is made of aluminum, which has the following constants: C_p= 0.9 J-gm^{-1}-K^{-1} and a density= 2.701 gm-cm^{-3}. The wall thickness of the inner chamber, taken to be 1 mm (~0.040"), is an average value since the chamber will have flanges and fittings but structurally is not required to carry high-stress loads. We further assume that the cryocooler has a heat rejection capacity of 15 watts at 77 K and a T_z of 40 K (a temperature at which the heat rejection power goes to zero)[1]. Table B-1 below lists the numerical values of all the relevant parameters.

Table B-1. Basic Chamber Heat Transfer Parameters

		Substance Between Inner and Outer Chamber Walls			
Parameter	Chamber Size	N_2	Xe	MLI	Equation No.
k, [W-m^{-1}-K^{-1}]		2.675x10^{-2}	5.485x10^{-3}	1.6x10^{-4}	
A, [cm^2]	60 cm	1.131x10^4			
	20 cm	1.2566x10^3			
m, [gm]	60 cm	3,055			
	20 cm	339			
mC_p, [J/K]	60 cm	2,749.3			
	20 cm	305.5			
kA/d, [W/K]	60 cm	1.191x10^0	2.442x10^{-1}	7.124x10^{-3}	
	20 cm	1.324x10^{-1}	2.713x10^{-2}	7.916x10^{-4}	
ΔT_{max}, [K]	60 cm	65.4	161.4	255.4	(7)
	20 cm	195.3	243.5	259.5	
T_f, [K]	60 cm	234.6	138.6	44.5	(2)
	20 cm	104.7	56.5	40.5	
τ, sec	60 cm	1728 (29 min)	4268 (1:11')	6753 (1:53')	(4)
	20 cm	706.5 (11.8')	715.2 (11.9')	762.2 (12.7')	

[1] Parameters are based on an available commercial cooler performance.

An important group of parameters, *kA/d*, with units of W/K appears in many expressions. These parameters can be interpreted in many ways. They represent the conductive heat load and should therefore be as small as possible. They also reflect the cooling power per degree K (below T_a) required to maintain the steady-state temperature. Thus, with N_2 between the large chamber walls, the required heat rejection power is **1.191 watts per every degree K below the ambient temperature**! Even with Xe fill, the required heat rejection power is a very high value of 0.2442 W/K. Vacuum with MLI gives a reasonable value of 0.0071 W/K.

The ΔT_{max} is limited at best to the temperature at which the cryocooler loses its cooling capacity, T_Z. In an ideal situation, without conductive heat load (*kA/d*=0), Eq. (7) indeed simplifies to $\Delta T_{max} = T_a - T_z = T_a - T_f$, where the second equality comes from the definition. Hence $T_f = T_Z$. As the value of *kA/d* increases, the maximum temperature difference becomes smaller, and as Table B-1 indicates not much cooling is achievable in such cases (e.g., N_2 or Xe). The lowest achievable temperature, can only be reached asymptotically, and in practice never achieved.

Another group of variables makes the characteristic time, $\tau = mC_p/(q_o + \frac{kA}{d}) \approx mC_p/q_o$. The approximation here applies to a case of a low conductive load. This group is the ratio between the thermal mass of the inner chamber, in J/K, and the cooler's heat rejection rate, in W/K. It is an indication of how long the cooler must operate and reject heat from the thermal mass in order to e-fold (63%) the ΔT. A low value of the thermal mass and a high value of the cooler's capacity are desired. It should be noted, however, that as the conductive load increases, the characteristic time gets smaller. This, however, is not an indication that less time is required for the cooling of the chamber; it rather indicates that a smaller ΔT_{max} is achievable, and, therefore, with the given cooling power, requires less time to approach the minimum temperature.

Effect of flanges, and ports on chamber cooling

In Table B-1, we observe that with the MLI, the chamber's final temperature is very close to the cooler's limit, T_Z. The analysis, obviously assumed that all the conductive loads come through the insulation which in the case of MLI is very effective. In reality the chamber has ports and flanges which provide additional conductive paths. It is hard to estimate at this time what the conductive load will really be. But one can parametrically look at the effect of an increased conductive load. We do this by arbitrarily multiplying the conductive load term, *kA/d*, by a factor *n*. Table B-2 shows some drastic changes to the parameters under such circumstances.

The large (60 cm) chamber with the MLI can be cooled only to 79 K, as compared with the previous 44.5 K, and the cooling time is reduced by about 15 minutes. Obviously, if the conductive loads through such fittings and flanges are larger, the chamber performance is impacted accordingly.

Table B-2: Basic Chamber Heat Transfer Parameters for nkA/d [1]

		Insulation Between Chamber Walls			
PARAMETER	CHAMBER SIZE	N_2	XE	MLI	EQUATION NO.
ΔT_{max}, [K]	60 cm	8.45	36.6	220.7	(7)
	20 cm	60.3	154.9	255	
T_f, [K]	60 cm	291.6	263.4	79.3	(2)
	20 cm	239.7	145.1	45.05	
τ, sec	60 cm	223 (3.7 min)	967 (16.1')	5834 (1:37')	(4)
	20 cm	177 (2.9')	455 (7.6')	749 (12.5')	

[1] $n = 10$

Radiative load

The addition of the radiation makes the equation nonlinear and not amenable to a closed-form analytical solution. It is not the intent of this brief analysis to perform numerical solutions, although these are straightforward. The purpose of this analysis is to assess the impact of the radiative load on the parameters which were introduced earlier, and to obtain a feel for their magnitude. These objectives can be accomplished by analytical treatment of the equations. In the first case we assume no radiation shielding between the chamber walls; shielding will be introduced later.

We first introduce an additional nomenclature; all surfaces facing inward have low emissivity, ε_i, to reduce the radiation from the outer shell into the inner shell. All surfaces facing outward have a high emissivity, ε_0, to increase radiation from the inner shell to the outer one.

Hence, Eq. (1) is rewritten with radiation.

$$-mc_p\frac{dT}{dt} = q_o(T - T_z) - \frac{kA}{d}(T_a - T) - \sigma A(\varepsilon_i T_a^4 - \varepsilon_o T^4) \tag{8}$$

where σ is Stefan-Botzman constant ($5.67\text{x}10^{-12}$ W-cm^{-2}-K^{-4}). As before, we can look at the steady-state solution first.

$$T = \frac{q_o T_z + \frac{kA}{d}T_a + \sigma\varepsilon_i A T_a^4}{q_o + \frac{kA}{d} + \sigma\varepsilon_i A T_f^3} = T_f \tag{9}$$

Eq. (9) is similar to Eq (2) and the additional terms are due to the radiative load. However, because of the nonlinearity, the solution is not in a closed form. In fact a trail-and-error solution is required. First a guess value of T_f is made and plugged into the denominator, solving for T_f. Based on the answer, a new guess is made and the process repeated as necessary until convergence (a process which is easily implemented on a spread sheet). Under some conditions, however, this can be avoided. When the ratio $\frac{\varepsilon_o T_f^4}{\varepsilon_i T_a^4} << 1$ Eq. (9) can be approximated as:

$$T = \frac{q_o T_z + \frac{kA}{d} T_a + \sigma \varepsilon_i A T_a^4}{q_o + \frac{kA}{d}} = T_f \tag{9a}$$

and Eq (7) is modified as follows:

$$\Delta T_{max} = \frac{q_o (T_a - T_z) - \sigma A \varepsilon_i T_a^4}{q_o + \frac{kA}{d}} \tag{7a}$$

We can examine the range of conditions under which the above approximation is reasonable. For T_a=300 K room temperature, the ratio between the inner wall to the outer radiation is 0.59 at T_f=200 K (inner wall temperature), 0.187 at 150 K, 0.037 at 100 K. The decision when the approximation is adequate is based on value judgment. For our purposes, though, T_f<200 K is considered adequate. For the purpose of these analyses we assume $\varepsilon_i = 0.3$;and $\varepsilon_o = 0.9$.

The term $\sigma \varepsilon_i A T_a^4$ appears in both equations (9a) and (7a) and has the following value for an outer chamber wall at room temperature

$$\sigma \varepsilon_i A T_a^4 = \begin{cases} 155.8 & \text{for 60 cm chamber} \\ 17.31 & \text{for 20 cm chamber} \end{cases}$$

To examine the effect of the radiative load we compare the values of T_f and ΔT_{max} for the various cases reviewed so far. We treat only the MLI cases since the other cases do not seem to have a practical value. A summary of the results is shown in Table B-3.

Table B-3. Summary of Thermal Loads Effect for MLI Chamber

Mode of Thermal Load	Chamber Size	kA/d	$n kA/d$	kA/D with Radiation
ΔT_{max}, [K]	60 cm	255.4	220.7	0[1]
	20 cm	259.5	255	216.3
T_f, [K]	60 cm	44.5	79.3	300
	20 cm	40.5	45.05	83.7

[1]Obviously, the assumption allowing the approximation in Eq. (7a, and 9a) is invalid in this region

Note: $\varepsilon_i = 0.3$, $\varepsilon_o = 0$

The largest chamber that can be cooled to T_f<200 K can be found from Eq. (9a), subject to the approximation invoked earlier. Eq. (9a) is solved for the area A:

$$A = \frac{q_o (T_f - T_z)}{\sigma \varepsilon_i T_a^4 + \frac{k}{d}(T_a - T_f)} \tag{10}$$

By using various values for T_f in Eq. (10), one can determine the chamber size which can be cooled to that temperature. Before plugging numbers into the equations, however, the effect of radiation shielding is reviewed and a similar equations will be derived for a chamber with one or

more radiation shields. The effects of radiative heat load with and without shielding will be then evaluated with numerical examples.

Transient equation

Restricted to the approximation as expressed earlier, T_f<200 K, the solution to the transient equation is as before given in Eq. (5), and where the characteristic time, τ, is given in Eq. (4), and T_f in Eq. (9a).

Radiation shielding

It is assumed that a single radiation shield is inserted between the outer and inner chamber walls. The shield, as before, has an emissivity ε_o on the side facing the outer wall, and emissivity ε_i on the side facing the inner wall. At steady-state conditions, the shield, at a temperature T_s exchanges radiation with the inner and outer walls but the heat fluxes in and out are balanced. Therefore, an equilibrium exists as follows:

$$\sigma A[\varepsilon_i T_a^4 + \varepsilon_o T^4] = \sigma A[\varepsilon_i T_s^4 + \varepsilon_o T_s^4] \tag{11}$$

Solving Eq. (11) for T_s yields:

$$T_s^4 = \frac{\varepsilon_i T_a^4 + \varepsilon_o T^4}{\varepsilon_i + \varepsilon_o} \approx \frac{\varepsilon_i}{\varepsilon_i + \varepsilon_o} T_a^4 \tag{12}$$

The approximation in Eq. (12) holds only for the conditions discussed earlier (i.e., $\frac{\varepsilon_o T_f^4}{\varepsilon_i T_a^4} << 1$) which in our case we have selected as T<200 K. The shield temperature can now be obtained as $T_s = [\frac{\varepsilon_i}{\varepsilon_i + \varepsilon_o}]^{1/4} T_a = 212\text{K}$ (for T_a=300K). The radiative load on the inner wall is now based on T_s, and the steady-state solution is:

$$T_f = \frac{q_o T_z + \frac{kA}{d} T_a + \sigma \varepsilon_i A T_s^4}{q_o + \frac{kA}{d}} \tag{13}$$

Solving for the chamber size, A, modifing Eq. (10), yields:

$$A = \frac{q_o (T_f - T_z)}{\sigma \varepsilon_i T_s^4 + \frac{k}{d}(T_a - T_f)} \tag{10a}$$

We are now in a position to introduce a few values into Eq. (10) and (10a). Table B-4 summarizes the results, showing the largest chamber diameter which can be cooled to 200 K and to 100 K based on the radiative (and conductive) thermal loads, with and without radiation shielding. The table assumes the same numerical parameters as those throughout this analysis (e.g., Cooler power which is temperature dependent with nominal 15 watts at 77 K, and zero power at 40 K, MLI or equivalent quality material in vacuum-jacketed chamber wall, etc.)

Table B-4. Chamber Size and Cooling Capacity

Cooling Temperature, K		200	100
Maximum Chamber Diameter, [cm]	No shield	38.4	23
	Single shield	76.3	46.3

Multiple radiation shields can be applied, and as long as the radiation between the adjacent shields meets the criteria for the approximation such as the lower temperature layer is much cooler and therefore its radiation is negligible compared with the radiation form the higher temperature layer, one can show that the most inner shield temperature is given by:

$$T_s^4 = \left\{\frac{\varepsilon_i}{\varepsilon_i + \varepsilon_o}\right\}^n T_a^4 \qquad (14)$$

As Eq. (14) shows, additional improvements may be gained by multiple shielding, at the cost, however, of increased mechanical complexity. It seems that a single shield may be adequate **and necessary** for the purpose of the GGSF chamber.

Summary and Conclusions

An analytical assessment of the chamber cooling was conducted. The thermal equation was described and a close-form analytical solution derived for some simple cases. The steady-state and the temporal solutions were reviewed and the dominating parameters extracted. A cryocooler with 15 watts at 77 K was assumed in the analysis; other assumptions were made regarding the emissivities of the surfaces and the dimensions of the chamber. The major points of the analysis are summarized below.

1. The chamber cooling is described by an exponential behavior with a characteristic cool-down time τ and an asymptotic lower temperature limit characterized by ΔT_{max} , the maximum cooling below the initial temperature.
2. ΔT_{max} is a function of the cryocooler heat rejection power less the combined radiative and conductive heat load. It does not depend on the thermal mass of the chamber.
3. τ is a function of the thermal mass of the chamber and the heat rejection power of the cryocooler.
4. The characteristic cooling time, τ, is an indication of the required cool-down time and can be used as follows: the time required to cool the chamber to a ΔT which is, say, 90% of ΔT_{max} , is $t/\tau = -\ln(1-0.9) = 2.3$, i.e., it takes 2.3 times the characteristic time to reach 90% of the maximum cooling possible.
5. Conductive heat loads must be reduced significantly; a vacuum-jacketed, double-walled chamber construction is required if cooling is needed.
6. With good thermal insulation (i.e., MLI in a vacuum) the radiative heat load is dominant and limits the minimum temperature the chamber can be cooled down.
7. Radiation shielding is required both for the small and large chambers; without the shielding very little cooling can be accomplished with the available power.
8. The maximum chamber diameter which can be cooled to 200 K without radiative shielding is about 38 cm, and with shielding is 76 cm. The largest chamber which can be cooled to 100 K without shielding is only 23 cm diameter and with shielding is 46 cm.
9. A second shield may significantly improve the performance.

10. The cooling time for a large chamber is on the order of several hours, and over an hour for the small chamber.
11. Based on these calculations and assumptions, in order to achieve the desired temperature in a reasonable time period, the large chamber requires heat rejection power of well over 10 watts at 77 K.
12. Detailed numerical analysis of chamber performance will have to be performed once the chamber design is available and the cooler characteristics known.

Appendix C
A Brief Review of Recent Cryocooler Developments[1]

Several recent developments in the cryocooling business may have relevance to the GGSF program. Representing the state of the art in this technology they indicate what can and what can not be done. In general the cryocoolers are divided into long-life (space qualified) and short-life type (tactical) devices. Since the coolers typically contain a pump/compressor the long-life devices are designed with air/magnetic bearing or flexure-diaphragms to avoid friction and wear (which ultimately determines the life duration). Tactical coolers (for IR detectors) are short-life devices and are not expected to survive for very long continuous operations. A third type of coolers are the laboratory devices; these systems typically are large in size, weight, and consume much electrical power. Manufacturers of some laboratory systems report MTBF of up to 40,000 hours. The selection of the cryocooler for the GGSF must consider all the trades between power, size, weight, life-time, etc. Again, the considerations and trades discussed here assume that no cryogenic liquids are allowed on-board the U.S. module and that other type of cooling is to be used. In terms of cooling temperatures, what can be accomplished?

A. 4 K-class systems are available without LHe:
   1. Two commercial systems (about 200 lb, using a lot of wall-plug power) are available in a 1/4 watt at 4.2 K size. Both use a staged system with a cryopump and a Joule-Thompson (JT) stage (which is a compressed gas system).
   2. ESA with RAL (Rutherford-Appleton Lab) are in the process of developing a 5 to 10 mW at 4 K space cooler. This technology is expected to emerge in no less than 5 years into the future.
   3. NASA/GSFC is about to issue, in 1992, an RFP for a 4 K cooler; again a 5-year schedule is expected.
   4. GSFC has an existing contract with Creare for a technology demonstration of a 1/4 watt, 4 K cooler. Again this is not yetoff-the-shelf technology.

B. In the 30 K cooler category:
   1. GSFC has two on-going contracts with Creare and Ball (started in 8/91) which are about 3 to 5 years from reliable technology demonstration.
   2. RAL with BAe have developed for ESA a 300 mW at 30 K (70 watts electrical) system which is space-qualified and running.
   3. A two-stage pulsed tube cooler is being demonstrated at TRW. No moving parts; not yet space qualified.

C. In the 60 to 80 K range one can find:
   1. BAe, 0.8 watt, at 80 K, 40-watt electrical system: commercially available, space-qualified by ESA.
   2. Lucas and Lockheed may have similar systems (qualification status?)
   3. The Air Force/SSC is working with Hughes (HAC) on a 2-watt, 65 K, 70-watt electrical demonstration program.
   4. Creare has a similar program to be demonstrated in 1992.

In summary, two types of coolers are available: one is intended for the lab and is very large in size and power consumption; the other is for tactical or space-borne systems and has a very

[1] See a recent article in AW&ST, April 6, 1992, pg 41-43.

small cooling capacity. The latter are typically used to cool IR detectors which are no larger than a computer chip, mounted in a dewar with radiation shielding and cooled windows. Otherwise, the use of LHe and LN_2 is required for achieving the low temperatures. For example, laboratory type mechanical refrigerators exist that use helium and can reach very low temperatures. These devices, however, use a very large compressor that often operates on 208 to 400 VAC, 3-phase systems.

For the purpose of this study it is assumed, however, that cryogenic liquids are not allowed on board the U.S. module lab, so this option is not considered. Further, for a facility which is intended to operate over extended periods of time, the storage and resupply of cryogenic fluids would create a logistics hardship. The availability of cryogenic fluids and their use for the GGSF will have to be assessed as the SSF constraints clarify.

The GGSF would require a cryocooler in the order of 10 to 20 watts at 40 K and be limited to no more than 1,000 watts of electrical power. The cooler should be as small as possible and have a life time of several thousand hours.

Appendix D
High Vacuum Pumping Brief Summary

This appendix provides a brief summary of potentially applicable pumps for the high vacuum range for the GGSF. Table D-1 provides a summary of the principle of operations of several pumps with specific emphasis on their applicability for space-borne application. A chart showing the operating range of various vacuum pumps is shown in Figure D-1. Of these pumps, several were reviewed in some detail.

Table D-1. Vacuum Pumps Options for GGSF

PUMP FAMILY	PRINCIPLE OF OPERATION
	Kinetics Pumps
Fluid Entrain-ment	Ejector: Typically used for medium vacuum range; requires high-speed flow of entrainment fluid (e.g., steam or another gas); the high velocity flow transfers momentum to the pumped fluids and entrains it along the way; the flow must then be discharged; space-borne applicability is not promising since it uses large volumes of consumables.
	Diffusion: Like an ejector pump, low-vapor-pressure oil (or mercury vapor, etc.) is boiled and sprayed to entrap the pumped gas molecules; the oil condenses on the walls and flows into a pan (gravity flow), boiled, and recycled; the system recycles the working fluid but is inappropriate for space-borne environment.
Drag Pumps	Turbomolecular: This system operates like a very fast (50,000 rpm) gas-turbine; molecules that wonder into the path of the rotating machinery are swept out; some pumps use magnetic bearings and do not require lubrication; due to the high rotating speed both vibrations and sound are at frequencies which can not be perceived; perhaps most appropriate for space applications.
	Entrapment Vacuum Pumps
Getter Pumps	Sputter Ion: Use high voltage and magnetic field (~0.1 T) to ionize gas which sputters a cathode material (e.g., titanium). The titanium deposits on other locations acting as a getter film; may be appropriate for μ-g applications.
	Sublimation: A sorption pump, uses a getter material (e.g., titanium) which is evaporated from a resistance-heated wire and deposited on a cold inner wall; gas molecules which impinge on wall are bound by chemisorption; ideal as a booster pump for other systems; may be appropriate for μ-g.
Cryo-pump	Pumping by condensation is used for most gases at temperatures in the 20 to 30 K range; achieved by a closed cycle He refrigerator; permanent gases (Ne, He, and H_2) are pumped by adsorption in activated charcoal; to reach 20 K, an 80 K cold shield is used (LN_2 cooled).

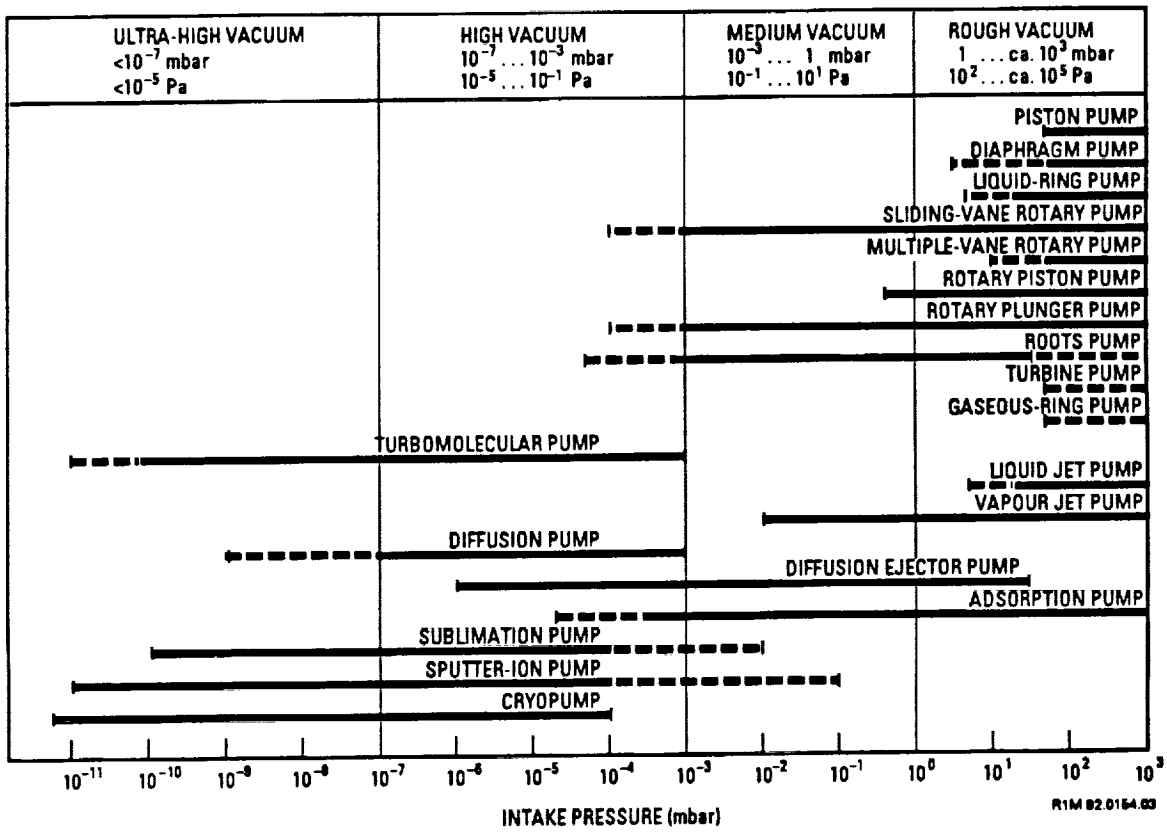

Figure D-1: Range of Vacuum Pump (dashed line indicates extended range)

APPENDIX E

PARTICLE BALLISTICS IN TEST CHAMBER

AND

THE FEASIBILITY OF MICRO-G EXPERIMENTS IN A CONFINED CHAMBER

1. Equation of Motion and Solution

The fundamental equation of motion in the plane of the gravity vector for a particle subject to drag and gravity forces is:

$$-F_D \pm mg = m\frac{dV}{dt} \tag{1}$$

Where the first term is the drag force, in the opposite direction to the velocity vector, and the ± sign in front of the gravity force term depends on whether the particle moves in the direction along g (+ sign), or against g (- sign). For motion in a plane normal to the gravity vector, this term is set to zero.

The drag force, F_D, is obtained from the conventional correlation for a sphere:

$$F_D = \frac{1}{2}\rho_g V^2 C_D A \tag{2}$$

Here, the velocity is the relative speed between the sphere and the air. The drag coefficient for Stokes' flow is commonly:

$$C_D = \frac{24}{Re} \tag{3}$$

where Re is the Reynolds number. For rarefied flow, in the slip, transition, and free molecular regimes the Millikan correction gives:

$$C_D = \frac{24}{Re}\left[\frac{1}{1+\frac{2\lambda}{d_p}(A+Be^{-Cd_p/2\lambda})}\right] \tag{4}$$

where λ is the mean free path (MFP), and the ratio λ/d_p is the Knudsen number, and A, B and C are constants. By substitution of all the terms into Eq. (1) and rearrangement, one obtains:

$$\frac{dV}{dt} + \frac{V}{\tau} \pm g = 0 \tag{5}$$

and where we define a characteristic time, τ,

$$\tau = \frac{\rho_p d_p^2}{18\mu}\left[1+\frac{2\lambda}{d_p}(A+Be^{-Cd_p/2\lambda})\right] \tag{6}$$

Here, the term in front of the brackets is the common characteristic time for a sphere in Stokes' flow, and the term inside the brackets is the correction for rarefied flow.

The mean free path is obtained for any gas from the relationship $\lambda \cdot P = C^*$ in which C^* is a gas-specific constant.

Let the particle have an initial velocity V_i. The particle velocity, V, and travel distance, S, are obtained by twice integrating Eq. (5),

$$V = V_i \exp\left(-\frac{t}{\tau}\right) \pm g\tau\left[1 - \exp\left(-\frac{t}{\tau}\right)\right] \tag{7}$$

and

$$S = V_i \tau\left[1 - \exp\left(-\frac{t}{\tau}\right)\right] \pm g\tau\left[t - \tau\left(1 - \exp\left(-\frac{t}{\tau}\right)\right)\right] \tag{8}$$

where τ is a characteristic time derived earlier.

Several ballistic characteristics of the particles are derived from these equations.

2. Particle Stopping Distance

For particle collision experiments: the distance a particle with an initial velocity V_i travels before coming to a complete stop can be found from Eq. (8). Assume that the direction of motion is in a plane normal to the gravity vector, then:

$$S(t) = V_i \tau(1 - e^{-t/\tau}) \tag{9}$$

and,

$$S_{stopping} = V_i \tau \tag{9a}$$

3. Particle Ballistic

In the following the initial particle velocity is assumed to be zero and we check the solution in various limiting conditions for verification.

3.1 Characteristic Time

In case $P \to \infty$, the MFP goes to zero, and the exponential term in the Millikan correction also goes to zero. In that case we obtain the conventional particle characteristic time:

$$\tau = \frac{\rho_p d_p^2}{18\mu} \tag{10}$$

For the case $P \to 0$ we get $\lambda \to \infty$ and the exponential term in Eq. (6) goes to 1. In that case:

$$\tau = \frac{\rho_p d_p^2}{18\mu}[1 + 2\lambda/d_p(A + B)]$$

$$\approx \frac{\rho_p d_p}{18\mu} \cdot \frac{2C^*}{P}(A + B) \qquad (11)$$

i.e., the characteristic time goes inversely like the pressure. As the pressure goes to zero, the characteristic time goes to infinity. Also, the dependence on the particle diameter is linear.

3.2 Particle Velocity

From Eq. (7) at no initial velocity, the following limits are calculated.

As $t/\tau \to 0$ (i.e., the MFP becomes very large) the exponent may be expanded into Taylor Series as follows:

$$e^{-t/\tau} \approx 1 - \frac{t}{\tau} + \ldots \qquad (12)$$

and therefore,

$$V = gt \qquad (13)$$

which is the well known case of free fall in vacuum!

The other limit as $t/\tau \to \infty$, we get

$$V = g\tau \qquad (14)$$

which is the common, well known, equation for the terminal velocity.

3.3 Settling Distance

From Eq. (8) assuming no initial velocity, the following limiting cases are calculated.

As $P \to 0$, $\tau \to \infty$ and the following Taylor Series expansion is used:

$$e^{-\frac{t}{\tau}} \approx 1 - \frac{t}{\tau} + \frac{1}{2} \cdot \frac{t^2}{\tau^2} + \ldots$$

therefore,

$$S = \frac{1}{2} \cdot gt^2 \qquad (15)$$

which is the settling distance in a vacuum.

In the other limit, $P \to \infty$, and for a long period relative to the characteristic time (i.e., $t/\tau \to \infty$), the equation yields:

$$S = g\tau(t - \tau) \qquad (16)$$

The settling distance is linear with time (because the speed is constant). Note this equation only holds once the terminal velocity has been reached.

The following values were used in the calculation:

A = 0.864, B = 0.290, C = 1.25 (see Carlson, D.J. and Hoglund, R.F., "Particle Drag and heat Transfer in Rocket Nozzles," AIAA Journal, Vol. 2, No. 11, Nov. 1964). No compressibility effects are included (i.e., Mach number must be low, say, less than 0.1), $C^* = 6.67 \times 10^{-3}$ cm-mbar, $\mu = 1.971 \times 10^{-5}$ Kg/m-s, $g/g_0 = 10^{-5}$, $\rho_p = 1$ g/cc.

A plot of the equations solved herein is attached (Figure E). For simplicity we combined several parameters and show the plots in terms of quantities which are important for the experimenter such as particle size, pressure, etc. The Knudsen number and the MFP are "hidden" parameters in the plots since these are rarely known to the user. This approach simplifies the assessment of the experiment feasibility. The four plots in the figure correspond to equations 6, 8, 7, and 9, respectively.

The plots show that for long-duration experiments (more than several minutes), the characteristic time must be smaller than about 1.0 (Fig. E-2). From Fig. E-1, for a given particle size, the minimum pressure to meet this requirement can be selected. Fig. E-3 shows the particle terminal velocity.

The stopping distance of most small particles is also very short according to Figure E-4.

For experiment conditions with other particle density, or other g-levels, and different temperatures the following corrections must be applied.

For a particle density different than 1 g/cm^3: τ, the characteristic time, is proportional to the new density.

For a g-level different than g=1.0E-05g_0: Both S, and V scale like g.

For a temperature different than T=300K: the characteristic time scales like $(300/T)^{1.5}$.

NOMENCLATURE

A, B, C	Constants	s	distance
A	projected area	t	time
C_D	drag coefficient	v_i	initial velocity
d_p	particle diameter	v	velocity
F_D	drag force	τ	characteristic time
g	gravitational acceleration	ρ	density
g_0	g at earth's surface	λ	mean free path
m	mass	μ	viscosity
p	pressure		
Re	Reynolds Number		

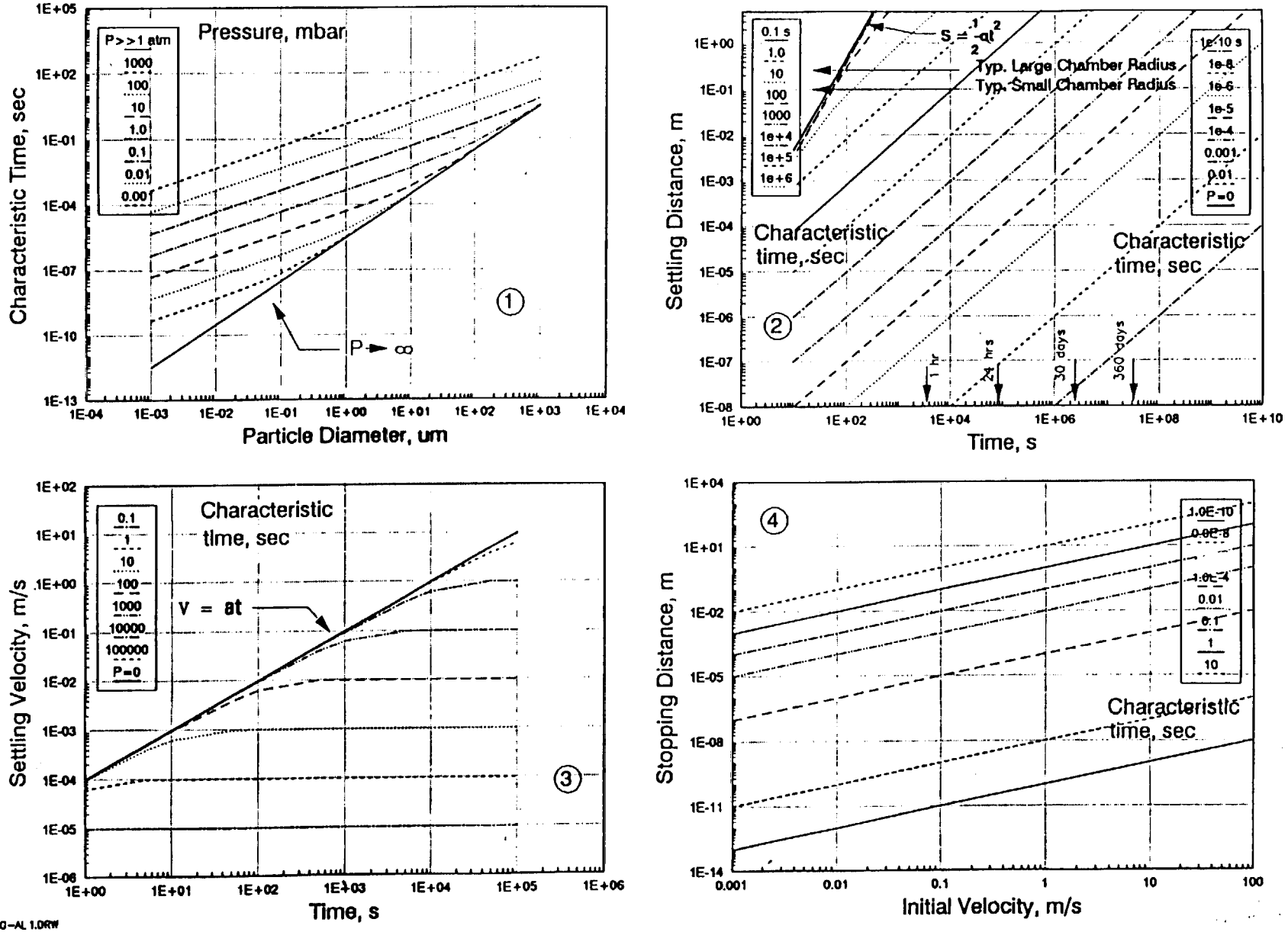

Figure E Particle Ballistics at 10^{-5}g

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

The Gas-Grain Simulation Facility (GGSF) is a facility-type payload to be included in the Space Station Freedom (SSF). The GGSF is a multidisciplinary facility that will accommodate several classes of experiments, including exobiology, planetary science, atmospheric science, and astrophysics. The physical mechanisms envisioned to be investigated include crystal growth, aggregation, nucleation, coagulation, condensation, collisions, fractal growth, cycles of freezing and evaporation, scavenging, longevity of bacteria, and more. TRW performed a Phase A study that included analyses of the science and technical (S&T) requirements, the development of facility functional requirements, and a conceptual design of the facility. This report summarizes the work that was performed under Stage 1 of the Phase A study and the results to date. In this stage, facility definition studies were conducted in sufficient detail to establish the technical feasibility of the candidate strawman experiments. The studies identified technical difficulties, identified required facility subsystems, surveyed existing technology studies and established preliminary facility weight, volume, power consumption, data systems, interface definition, and crew time requirements. The results of this study served as the basis for Stage 2 of the Phase A study in which a conceptual design and a reference design were performed. The results also served as a basis for a related study for a Gas-Grain Simulation Experiment Module (GGSEM), which is an apparatus intended to perform a subset of the GGSF experiments on board a low-Earth-orbiting platform.

14. SUBJECT TERMS

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