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REFERENCE EARTH ORBITAL RESEARCH AND APPLICATIONS INVESTIGATIONS

(BLUE BOOK)

VOLUME III • PHYSICS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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15 January 1971

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PREFACE

The purpose of the preliminary edition of the "Reference Earth Orbital Research and Applications Investigations" set forth in this document is to:

a. Provide criteria, guidelines, and an organized approach for use in the Space Station and Space Shuttle Program Definition Phase and ancillary studies in designing a flexible, multidisciplinary orbiting space facility and logistics system.

b. Define a manned space flight research capability to be conducted in earth orbital Space Stations and Shuttles.

c. Provide a basis for potential follow-on programs.

The term "Functional Program Element" (FPE) used in this document describes a gross grouping of experiments characterized by the following two dominant features:

a. Individual experiments that are mutually supportive of a particular area of research or investigation, and

b. Experiments that impose similar and related demands on the Space Station Support Systems.

The research and applications investigations as set forth herein depart from a heterogeneous collection of individual experiments and are designed toward a "research facility" and "module" approach. The term FPE and "module" are used somewhat interchangeably in this publication although this relationship is unintentional. Thus, a particular FPE may be described which does not fully utilize the capability of a complementary module but would, however, permit flexibility in experiment planning.

Functional Program Elements and experiments covered in this document are envisioned for flight with the initial Space Station and the Space Shuttle. Only those FPE's and experiments which can reasonably be expected to be accomplished during the first few years of the Space Station and Space Shuttle have been described in detail in this document. However, for the most part, these FPE's are considered to be open-ended so that their utility could be extended.

This publication is applicable to all NASA program elements and field installations involved in the Space Station and Space Shuttle program.

The supply of this document is limited. Therefore, for those procurement actions involving only a certain portion (or portions) of this handbook, the cognizant NASA installations shall abstract from this handbook only such portions as apply to a given RFP or contract action.

This publication was prepared in conjunction with NASA Headquarters Program Offices and field installations involved in payload planning and with industry participation. It is an updated and revised version of the Candidate Experiment Program for Manned Space Stations, NHB-7150.xx, dated September 15, 1969 and the changes thereto dated June, 1970. These earlier versions are hereby cancelled.

The material contained in each volume has been produced under the guidance of Review Groups composed of scientific personnel at NASA Headquarters, MSFC, LaRC, MSC, LeRC, GSFC and ARC. The purpose of this effort was not only to revise and update the experiment programs but also to establish the Space Shuttle as well as the Space Station requirements.

Volume I, Summary, presents the background information and evolution of this document; the definition of terms used; the concepts of Space Shuttle, Space Station, Experiment Modules, Shuttle-sortie Operations, and Modular Space Station; and in Section IV, a summary of the Functional Program Element (FPE) requirements is presented.

Volumes II thru VIII contain detailed discussions of the experiment programs and requirements for each discipline. The eight volumes are:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics
Volume IV	Earth Observations
Volume V	Communications/Navigation
Volume VI	Materials Sciences & Manufacturing
Volume VII	Technology
Volume VIII	Life Sciences

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INTRODUCTION

The Physics Discipline of the Blue Book includes four Functional Program Elements (FPE's):

a. Space Physics Research Laboratory

b. Plasma Physics and Environmental Perturbation Laboratory

c. Cosmic Ray Physics Laboratory

d. Physics and Chemistry Laboratory

The Space Physics Research Laboratory FPE describes a flexible space facility for performing experiments in the scientific categories of:

a. Atmospheric and magnetospheric science (including aurora)

b. Cometary physics

c. Meteoroid science

d. Astronomy (small telescopes)

The objective of the first category is to investigate the chemical and energy conversion processes of the thermosphere and dynamics of the magnetosphere. The second category will investigate possible causative mechanisms of cometary spactra. The meteoroid experiments have as objectives the determination of meteoroid mass, velocity, composition, trajectory and origin. Astronomy (small telescopes) experiments will complement the investigations of the larger experiments (such as Advanced Astronomy Module or the UV Stellar Survey Module of the Space Station) particularly in UV observations.

The Space Physics Research Laboratory includes 25 instruments in the five categories of optical instruments, ambient environment sensors, particle sensors, gaseous release devices, and meteoroid sensors. Spectral and geometric flexibility is emphasized by virtue of the ability to select appropriate instruments for mounting on independently controllable gimbals which are deployable via airlocks.

The Plasma Physics and Environmental Perturbation Laboratory FPE has the objective of defining a facility which is capable of performing experiments involving perturbation and observation of the plasma of the magnetosphere. Four experiments were selected as typical of those to be performed:

a. Exploration of the wake generated in the ionospheric plasma by the motion of the spacecraft through it

b. Investigation of plasma resonances and their harmonics

c. Investigation of wave/particle interactions

d. Investigation of electron and ion beam propagation

The facility which is described includes a family of instruments for making measurements of the plasma in the proximity of the spacecraft and about remotely deployed bodies. The instruments will be used in conjunction with remotely deployed satellites, both for creating and measuring wakes, as well as on booms deployed from the laboratory itself. RF transmitters and particle accelerators are described for perturbing the plasma. Observations of effects are indicated from the Earth as well as from the spacecraft and subsatellites.

The Cosmic Ray Physics Laboratory will be an orbiting facility designed to investigate the astrophysical properties of cosmic ray phenomena at energies greater than 10^{10} eV. A major design goal has been flexibility. Through manned participation it will be possible to rearrange experiments by selecting different combinations of sensor channels and related equipment.

Among the experimental goals are the accurate measurements of:

a. Flux of cosmic ray nuclei ($>10^{10}$ eV)

b. Charge composition of nuclei ($>10^{9}$ eV)

c. Electron-positron spectra ($>10^{10}$ eV)

d. Isotopic composition of light nuclei

e. To search for anisotropies in the above

f. To search for antinuclei, quarks, magnetic monopoles, or other such particles

The major elements of the facility are a cryogenic magnetic spectrometer, a total absorption detector, and four detector bays including one for extremely heavy nuclei (high-Z). The magnet and its helium dewar are an integral yearly replaceable unit. The total absorption detector is a heavy item which may be added in segments after the initial laboratory has been assembled and operated.

The Physics and Chemistry Laboratory FPE describes a multipurpose laboratory facility for performing original physics and chemistry experiments that make use of the unique environmental conditions available in space.

Among the important characteristics of the environment are zero-g, space vacuum, solar radiation, and the hypervelocity atomic, molecular and ion beam generated by the spacecraft moving at orbital velocity. Eight experiments were selected as typical of the requirements of this FPE:

a. Critical point phenomena

b. Gas-surface interactions

c. Molecular beam scattering

d. Heat transfer in a convectionless medium

e. Operational characteristics of chemical lasers

f. Flame chemistry and reaction kinetics at zero g

g. Quantum effects at low temperature and zero g

h. Gaseous reaction kinetics in space vacuum

The laboratory will have work stations which receive experiments packaged in standarized configurations as carry-on "suitcase" payloads for plug-in to the work stations. The laboratory will provide the necessary electrical power, gases, vacuum lines, and airlocks, as well as multipurpose test equipment and instrumentation. The laboratory comprises a basic complement of 13 equipment items and 24 items of supporting equipment.

Table 1 presents the Blue Book list of crew skills and the code numbers which are used in the tabular presentations of this volume.

Table 1. Crew Skills

1.	Biological Technician	14.	Optical Technician
2.	Microbiological Technician	15.	Optical Scientist
3.	Biochemist	16.	Meteorologist
4.	Physiologist	17.	Microwave Specialist
5.	Astronomer/Astrophysicist	18.	Oceanographer
6.	Physicist	19.	Physical Geologist
7.	Nuclear Physicist	20.	Photo Geologist
8.	Photo Technician/Cartographer	21.	Behavioral Scientist
9.	Thermodynamicist	22.	Chemical Technician
10.	Electronic Engineer	23.	Metallurgist
11.	Mechanical Engineer	24.	Material Scientist
12.	Electromechanical Technician	25.	Physical Chemist
13.	Medical Doctor	26.	Agronomist
		27.	Geographer

VOLUME III

SECTION 1

SPACE PHYSICS RESEARCH LABORATORY

SECTION 1

SPACE PHYSICS RESEARCH LABORATORY

1.1 GOALS AND OBJECTIVES

The purpose of the Space Physics Research Laboratory (SPRL) is to provide flexible facilities in space for conducting experiments relating to:

a. Atmospheric and magnetospheric science (including aurora)

b. Cometary physics

c. Meteoroid science

d. Astronomy (small telescopes)

The objectives of the atmospheric and magnetospheric science program are:

a. To investigate the chemical and energy conversion processes which control the structure of the thermosphere and through simultaneous measurement of its structural properties, the energy input parameters which control these properties and the airglow parameters which provide information on the rates of controlling aeronomic process.

b. To study such complex processes as quiet-time auroral precipitation and the dynamics of the magnetospheric substorm. These phenomena are thought to be caused by plasma instabilities involving magnetospheric field line reconnections and acceleration of particles by parallel electric fields and their precipitation into the high latitude ionosphere. In turn these are responsible for such atmospheric and terrestrial manifestations as flow of ionospheric currents, temporary changes in the magnetic fields, and visible auroral displays.

In the field of comet physics, one of the most significant problems is the determination of the physical mechanism or mechanisms responsible for the production of the observed radicals and ions. There has been produced, to date, very convincing evidence supporting a resonance fluorescence mechanism by solar electromagnetic radiation for most of the comet observed molecular and atomic emission, but there the success apparently stops. The problems of the mechanisms of dissociation and ionization of most of the stable parent molecules and product fragments remain unsolved.

In spite of many attempts to theoretically or experimentally ascribe these phenomena to orthodox theories of simple interactions between the molecules of the cometary atmosphere and the solar corpuscular or electromagnetic fields, little progress has been made. Most of these attempts fail by orders of magnitude to produce sufficient material quickly enough to be responsible for the cometary observations. It is in this area of mechanisms that it may be possible to gain some insight with the proposed gaseous release experiments.

The meteoroid experiments have among their objectives the determination of meteoroid mass, velocity, composition, trajectory, and origin. These measurements will add to, and complement earlier measurements made on meteoroid momentum and related flux density. These data may also be used to reduce uncertainties in erosion and penetration predictions which may possibly result in more effective future spacecraft designs.

With the exception of meteorites which have been altered by their flight through the atmosphere, we have had a close look at only one extraterrestrial object - the Moon. Whether meteoroids originate in the asteroid belts or are remnants of comets, they are composed of material in a primordial state. They are at least of as much importance in our understanding of cosmological processes as the Moon. Hence, experiments to determine their basic properties - origin, composition, physical properties, interplanetary distribution, size distribution, etc. - are significant and are justified from a strictly scientific point of view.

In addition, the impact of meteoroids on space vehicles is a hazard to their survival. From many cumulative years of exposure to the meteoroid environment with a spacecraft failure and from ground based and direct measurements of the meteoroid flux, it is evident that the hazard has not been great for the majority of past missions. However, more ambitious undertakings (space labs, interplanetary missions) will increase the exposure and thereby increase the probability of having a catastrophic encounter. Uncertainties in the meteoroid flux may have imposed a meteoroid protection weight penalty on the majority of spacecraft. An improvement in the reliability of hazard predictions could lessen the weight penalty without jeopardizing the mission or, conversely, provide convincing evidence that meteoroid protection is a necessary part of spacecraft.

From either scientific or engineering points of view, there are compelling reasons for comprehensive experiments on the characteristics of meteoroids.

The scientific objective of the astronomy (small telescopes) experiments is to compliment and supplement the astronomical investigations to be conducted with its larger cousins, such as the Advanced Astronomy Module, or the UV Stellar Survey Module of the Space Station.

There are a variety of investigations which can be conducted with a moderate size telescope as efficiently as, or even more efficiently than, with a large telescope. The reason is partly because there exists much work that does not require a great photon gathering capacity. Also, smaller aperture telescopes, designed to perform specific tasks, can be more efficient instruments for these specific tasks. It may be recalled that since completion of the famed 5.08 m (200-inch) telescope at Palomar Mountain, numerous smaller telescopes have been and are still being constructed as vital tools for astronomers. In analogy to the smaller ground-based telescopes, the small space station telescopes are intended to make space observations more easily accessible to the interested astronomers.

1.2 PHYSICAL DESCRIPTION

The ingredients of the space physics research laboratory are shown in Figure 1-1 in concept form. Table 1-1 identifies the family of instruments and devices which are required for performance of the four experiment categories listed on the left of the table. These instruments are typical of the experiment requirements, and their selection results from the representative experiments and observations which are discussed in each category.

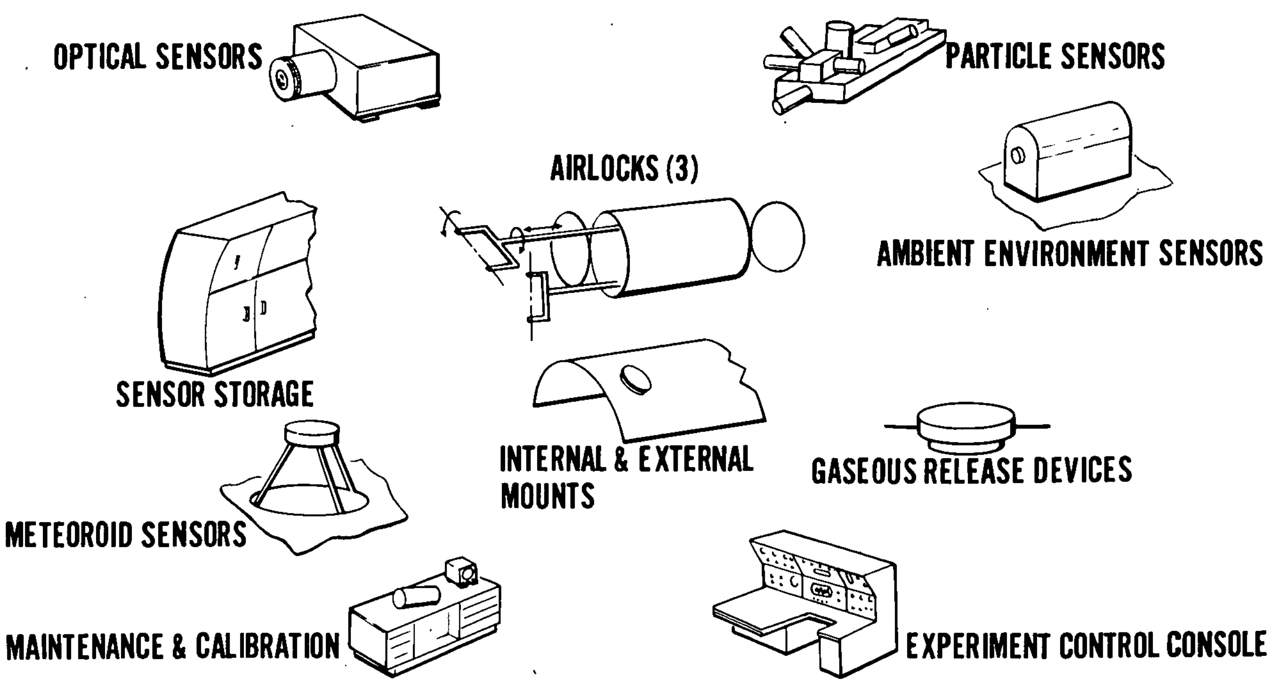


Figure 1-1. Conceptual Elements of the Space Physics Research Laboratory

In Table 1-1, the instruments are grouped in five categories as indicated at the top of the table. The optical sensors and the energetic particle sensors are the ones which will make most effective use of the three airlocks shown in Figure 1-1. Two of the airlocks are of the crder of 0.91 m (36 in.) diameter by 0.91 m (36 in.) long. One of them is 1.22 m (48 in.) diameter by 1.82 m (72 in.) long to accommodate the larger

Table 1-1. Instrument Requirements by Experiment Category

Astronomy (Small Telescopes)	Meteroroid Science	Cometary Physics	Atmospheric & Magnetospheric Science (Including Aurora)	INSTRUMENT	
			●	Photometric Cluster	Optical Sensors
●			●	Interferometer Spectrometer	
●		●	●	Scanning Grating Spectrometer	
●			●	EUV Spectrometer	
			●	Image Isocon Television	
●				Image Tube Optical System	
			●	Open Source Mass Spectrometer	Ambient Environment Sensors
			●	Closed Source Mass Spectrometer	
			●	Neutral Gas Temperature	
			●	Ion Mass Spectrometer	
			●	Ion Trap	
			●	Electrostatic Probe	
			●	Electric Field Probes	
			●	Flux Gate Magnetometer	
			●	Magnetometer Coil	
			●	VLF Sensor	
			●	Aluminum Foil Exposure Device	Energetic Particle Sensors
			●	Particle Sensor Cluster	
		●		NH_3 Release Device	Gaseous Release Devices
		●		ICN Release Device	
	●			Cosmic Dust Composition Analyzer	Meteoroid Sensors
	●			Optical Meteoroid Detector	
	●			Cosmic Dust Mass & Velocity Sensor	
	●			Thick Material Penetration Panels	
	●			Recoverable Panels	

EXPERIMENT CATEGORY

instruments such as the scanning grating spectrometer. Each airlock will include two extendible rails with provisions for three-axis pointing of the payload. Any combination of six instruments may be used simultaneously to examine various geometric and spectral zones.

The ambient environment sensors, gaseous release devices, and meteoroid sensors will be mounted externally on the spacecraft surface or on booms.

Within the spacecraft, provisions will be made for experiment control and monitoring, maintenance and calibration, as well as sensor storage. Data processing is expected to be provided by a separate central facility.

1.3 EXPERIMENT REQUIREMENTS SUMMARY

Tables 1-2, 1-3, 1-4, and 1-5 present, respectively, the experiment requirements for: (1) atmospheric and magnetospheric science (including aurora), (2) cometary physics, (3) meteoroid science, and (4) astronomy (small telescopes).

1.4 EXPERIMENT PROGRAM

1.4.1 ATMOSPHERIC AND MAGNETOSPHERIC SCIENCE (INCLUDING AURORA)

1.4.1.1 Scientific Objectives. A scientific objective of the SPRL is to provide a facility for investigating the chemical and energy conversion processes which control the structure of the thermosphere through simultaneous measurements of its structural properties, the energy input parameters which control these properties, and the airglow parameters which provide information on the rates of controlling aeronomic processes.

The principal goal of the atmospheric science portion of the program is to elucidate the chemical processes and the processes of energy absorption, conversion, and transport, which control the structure of the upper atmosphere below 300 km. Another goal is the continued investigation of the altitude region above 300 km during periods of both high and low solar activity. A third goal is the provision of a comprehensive survey of latitudinal variations of upper atmosphere properties at several different altitudes so that horizontal transport can be evaluated and related to vertical transport.

The SPRL will also provide a means of studying the quiet-time aurora and the magnetospheric substorm (westward surge and auroral breakup).

The object is to gain an understanding of:

a. Source of auroral precipitation

b. Energization mechanism

Table 1-2. Experiment Requirements Summary - Atmospheric and Magnetospheric Science (Including Aurora)

INSTRUMENT	WEIGHT KG (LBS)	VOLUME - m^3 (ft^3)	ENVELOPE - m (in)	POWER (WATTS)	CREW SKILLS	EXPERIMENT TIME (MAX.)	DATA REQUIREMENTS (MAX.)	ATTITUDE CONTROL	REMARKS
PHOTOMETRIC CLUSTER	13.6 (30)	.056 (2)	.61x.31x.31 (24x12x12)	25	6, 12	24 HOURS PER DAY FOR 4 DAYS	128 CH. 10 BITS 64 SPS	GIMBALLED NADIR TO ZENITH AND FORE & AFT.	
INTERFEROMETER SPECTROMETER	75 (166)	.34 (12)	.23x.3x.55 (9x12x21.5) .51 DIA x .76 (20 DIA x 30) .41x.48x.51 (16x19x20) .23x.48x.41 (9x19x16	457 STANDBY 457 AVG. 1137 MAX. TELESCOPE DRIVE MOTOR REQUIRES 400 WATTS FOR 1 ms EVERY SECOND	6, 12	24 HRS. PER DAY FOR 4 DAYS	40,000 BPS	LOS: ±2° RATES: .01°/SEC. ALT: ±2 Km	ENVELOPE INCLUDES ELECTRONICS, CONSOLE, & 16" CASSEGRAIN TELESCOPE
SCANNING GRATING SPECTROMETER	85 (186)	.48 (17)	.31x.41x1.02 (12x16x40) .51 DIA.x.76 (20 DIA.x30) .41x.48x.51 (16x19x20) .23x.48x.41 (9x19x16)	457 STANDBY 457 AVG. 1137 MAX. TELESCOPE DRIVE MOTOR REQUIRES 400 WATTS FOR 1 ms EVERY SECOND	6, 12	24 HRS. PER DAY FOR 4 DAYS	20,000 BPS	LOS: ±2° RATES: .01°/SEC ALT: ± 2Km	ENVELOPE INCLUDES ELECTRONICS, CONSOLE & 16" CASSEGRAIN TELESCOPE
EUV SPECTROMETER	11.4 (25)	.018 (0.65)	.31x.25 (12 DIA x 10)	16 AVERAGE 2 STANDBY	6, 12	24 HRS. PER DAY FOR 4 DAYS.	32 CH 40 SPS 10 BITS	TO BE POINTED AT AREAS OF INTEREST. NO WINDOWS, LENS, OR MIRRORS PERMISSIBLE ± 2 MIN.	
PARTICLE SENSOR CLUSTER	34 (75)	.085 3	.31x.31x.93 (12x12x36)	50	6, 12	3 HRS PER DAY FOR 10 DAYS.	192 CH. 10 BITS 128 SPS	GIMBALLED ZENITH TO NADIR AND FORE & AFT.	
IMAGE ISOCON TELEVISION	21 (46)	.033 (1.165) .027(REC) (0.965)	.19x.18x.54 (7.5x7.0x21.2) .22x.19x.29 (8.5x7.5x11.5) .19x.36x.39 (7.5x14.2x15.1) 1.02x.15x1.02 (4.0x6.0x4.0)	70 AVG 110 MAX	6,12	3 HRS. PER DAY FOR 10 DAYS	2 FRAMES PER SEC. FOR SURVEY. MAX. FRAME RATE FOR SELECTED 10 MIN. INTERVALS. $3x10^6$ BITS PER FRAME OR 240 KHz ANALOG BW	TO BE POINTED AT AREAS OF INTEREST.	USES 4 CHANNEL VIDEO RECORDER
OPEN SOURCE MASS SPECTROMETER	6.8 (15)	.01 (0.35)	ADJUSTABLE	8	6,12	24 HRS. PER DAY FOR 4 DAYS	405 BPS	FIXED TO S/C	
CLOSED SOURCE MASS SPECTROMETER	7.3 (16)	.013 (0.46)	.2x.25x.25 (8x10x10)	18	6, 12	24 HRS. PER DAY FOR 4 DAYS	540 BPS	FIXED TO S/C	
NEUTRAL GAS TEMPERATURE	6.8 (15)	.014 (0.5)	.2x.25x.28 (8x10x11)	10	6, 12	24 HRS PER DAY for 4 DAYS	540 BPS	FIXED TO S/C	
ION MASS SPECTROMETER	3 (6.5)	.005 (0.18)	.15x.15x.22 (6x6x8.5)	2	6, 12	24 HRS. PER DAY FOR 4 DAYS	810 BPS	FIXED TO S/C	
ION TRAP	3.4 (7.5)	.009 (0.32)	.18x.2x.25 (7x8x10)	10	6, 12	24 HRS PER DAY FOR 4 DAYS	1080 BPS	FIXED TO S/C	
ELECTROSTATIC PROBE	1.4 (3.0)	.0011 (.04)	.102x.13x.09 (4x5x3.5)	2	6, 12	24 HRS. PER DAY FOR 4 DAYS	540 BPS	FIXED TO S/C	
ELECTRIC FIELD PROBES	14 (30)	.056 (2)	.25 6-(10") SPHERES ON 6 BOOMS	10	6, 12	3 HRS. PER DAY FOR 10 DAYS	3 CH. 10 BITS 30 SPS	SIX 3 METER BOOMS	
FLUXGATE MAGNETOMETER	2.3 (5)	.0035 (.125)	.15x.15x.15 6x6x6	5	6, 12	3 HRS PER DAY FOR 10 DAYS	3 CH 10 BITS 30 SPS	MUST BE ON 10 M RIGID BOOM.	
MAGNETOMETER SEARCH COIL	2.7 (6)	.0007 (.025)	.19 DIA x .025 (7.4 DIA x1)	2	6, 12	3 HRS. PER DAY FOR 10 DAYS	5000 BPS		
VLF SENSOR	2.3 (5)	.0056 (.2)	LOOP ANTENNA	5	6, 12	3 HRS. PER DAY FOR 10 DAYS	90 KHz RECORD	ANT. ⊥ TO FIELD LINES	
ALUMINUM FOIL EXPOSURE DEVICE	3.2 (7)	.0085 (.3)	.31x.31x.05 12x12x2	0	12	5 DAYS OR MORE	PANEL TO BE RECOVERED	PANEL ON SIDE AWAY FROM EARTH	

Table 1-3. Experiment Requirements Summary - Cometary Physics

INSTRUMENT	WEIGHT KG (LBS)	VOLUME - m^3 (ft^3)	ENVELOPE - m (in)	POWER (WATTS)	CREW SKILLS	EXPERIMENT TIME (MAX.)	DATA REQUIREMENTS (MAX.)	ATTITUDE CONTROL	REMARKS
NH_3 RELEASE DEVICE	4.54-13.6 (10-30)	.1 (3.5)	.56 (22.6) DIA SPHERE	MOMENTARY SOLENOID RELEASE.	6, 12	30 MIN. PER RUN. NUMBER OF RUNS TBD FROM 3-10.	SEE SCANNING GRATING SPECTRO-METER.	RELEASE TO AVOID S/C SHADOW.	WEIGHT DEPENDS UPON FINAL DESIGN PRESSURE.
ICN RELEASE DEVICE	.68 CANISTER - (1.5) 6.8 BATTERIES - (15)	.0002 CANISTER - (.0075) .0025 BATTERIES - (.087)	CANISTER .113 (4.57) DIA x .02 (.8) BATTERIES .12x.12x.15 (5x5x6)	4000 WATTS FOR 1000 SECONDS.	6, 12	30 MIN. PER RUN NUMBER OF RUNS TBD FROM 3-10.	SEE SCANNING GRATING SPECTRO-METER.	RELEASE TO AVOID S/C SHADOW	
SCANNING GRATING SPECTROMETER	85 (186)	48 (17)	.31x.41x1.02 (12x16x40) .57 DIA.x.76 (20 DIA.x30) .41x.48x.51 (16x19x20) .23x.48x.41 (9x19x16)	457 STANDBY 457 AVG. 1137 MAX. TELESCOPE DRIVE MOTOR REQUIRES 400 WATTS FOR 1 ms EVERY SECOND	6, 12	30 MIN. PER RUN NUMBER OF RUNS TBD FROM 3-10	20,000 BPS	LOS: ±2° RATES: ±.01°/SEC. ALT: ±2 N.M.	ENVELOPE INCLUDES ELECTRONICS, CONSOLE & 16" CASSEGRAIN TELESCOPE

Table 1-4. Experiment Requirements Summary - Meteoroid Science

INSTRUMENT	WEIGHT KG (LBS)	VOLUME - m^3 (ft^3)	ENVELOPE - m (in)	POWER (WATTS)	CREW SKILLS	EXPERIMENT TIME (MAX.)	DATA REQUIREMENTS (MAX.)	ATTITUDE CONTROL	REMARKS
COSMIC DUST COMPOSITION ANALYZER	4.54 (10)	.028 (1) STOWED .09 (3) DEPLOYED	.31 (12) DIA x .4 (15.6) STOWED .31 (12) DIA x 1 (39.6) DEPLOYED	10	6, 12	5 DAYS PER DATUM APPROX.	2 EXPOSED FILM CARTRIDGES.	PREFERRED: GIMBALS MINIMUM: PARALLEL TO ECLIPTIC PLANE NOT TOWARD EARTH.	OSCILLOSCOPE AND CAMERA REQUIRED IN CREW-HABITABLE ENVIRONMENT.
OPTICAL METEOROID DETECTOR	34 (75)	.78 (28)	1 DIA x 1 (39 x 12 x 39)	7.5	6, 12	ENTIRE PERIOD OF SPACE STATION OPERATION.	264 BITS PER EVENT. 100 EVENTS PER DAY APPROX.	GIMBALS ±2° ACCURACY	
COSMIC DUST MASS AND VELOCITY SENSOR	6.1 (13.5)	.025 (0.9)	.61x.2x.2 (24x8x8)	1.5	6,12	ENTIRE PERIOD OF SPACE STATION OPERATION	48 BITS PER EVENT.	NONE	
THICK MATERIAL PENETRATION PANEL ASSEMBLY	865 (1909)	1.47 (48.5)	1.8x1.7x0.24 (72 x 66x 1) 6.1 x 8.4x0.24 (240 x 330 x 1)	<5	6, 12	ENTIRE PERIOD OF SPACE STATION OPERATION	2000 BITS PER SCAN. 1 SCAN PER DAY. TRANSMIT WHEN CONVENIENT.	NONE	ASSUME PANELS TO BE 1" THICK
RECOVERABLE PANEL ASSEMBLY	5.9 (13)	.047 (1.67)	1.52x.4x.08 (60x16x3	NONE	12	ENTIRE PERIOD OF SPACE STATION OPERATION	PANELS TO BE RECOVERED	NONE	

Table 1-5. Experiment Requirements Summary-Astronomy (Small Telescopes)

INSTRUMENT	WEIGHT KG (LBS)	VOLUME - m^3 (ft^3)	ENVELOPE - m (in)	POWER (WATTS)	CREW SKILLS	EXPERIMENT TIME (MAX.)	DATA REQUIREMENTS (MAX.)	ATTITUDE CONTROL	REMARKS
SCANNING GRATING SPECTROMETER	85 (136)	.48 (17)	.31x.41x1.02 (12x16x40) .57 DIA.x.76 (20 DIA.x30) .41x.48x.51 (16x19x20) .23x.48x.41 (9x19x16)	457 STANDBY 457 AVERAGE 1137 MAX. TELESCOPE DRIVE MOTOR REQUIRES 400 WATTS FOR 1 ms EVERY SECOND	6, 12	10-60 MIN.	20,000 BPS	LOS: ±2° RATES: ±.01°/SEC. ALT: ±2Km	ENVELOPE INCLUDES ELECTRONICS, CONSOLE & 16" CASSEGRAIN TELESCOPE
SPACE IMAGE TUBE OPTICAL SYSTEM	11 Kg (24)	.027 (.95)	.2 (7.9) DIA x .86 (34)	<1W SEE REMARKS	5, 12	1/3 SEC FOR BRIGHT SOURCES 5-15 MIN. FOR BACKGROUND LIMITED SOURCES	100,000 BPS FOR 1 FRAME/MIN.	≤.5°	USES TRACKING MOUNT OF SCANNING GRATING SPECTROMETER.

c. Plasma processes involved during the substorm

d. Changes in the magnetospheric geometry

e. Excitation of atmospheric constituents

Through the use of a large, manned, orbital facility for performing experiments in auroral physics, it will be possible to carry a large battery of diagnostic instruments at the same time in order to bring the full weight of a multifaceted approach to the study of a complex phenomenon.

In addition, only through the use of a scientist-astronaut is it possible to make on the spot decisions about the intelligent utilization of instruments to study these complex and time varying phenomena.

Data gathered during the long term observation program will be correlated with surface based measurements to provide maximum possible coverage.

1.4.1.2 Program Description. Most of the controlling chemical and energy conversion processes occur in the low-altitude region between 100 km and 250 km. It is here that ultraviolet radiation from the sun is absorbed, producing the ions and electrons of the ionosphere. The ions and electrons also recombine in this low-altitude region, and electron and ion densities at higher altitudes in the ionosphere are partly governed by processes occurring at the low altitudes.

Absorption of solar ultraviolet radiation initiates changes in the energy balance as well as chemical changes. Ultraviolet energy is converted into heat, causing electron and gas temperatures to rise. Heating is concentrated in the low-altitude region and the energy processes occurring in this region influence the temperatures at all altitudes.

In the topside ionosphere above about 300 km, electron and ion densities are influenced by ambipolar diffusion and electron and ion temperatures are influenced by thermal conduction and probably by plasma waves and energetic particles. These transport processes greatly complicate the theory of the topside and make an unambiguous interpretation of satellite measurements of ionospheric parameters very difficult. In the low-altitude region, on the other hand, the neutral density is high and transport phenomena are less important for the charged species. Thus densities and temperatures are determined by purely local processes. Chemical equilibrium governs the ion electron densities and equilibrium between heating and cooling rates governs the temperatures.

Theoretical knowledge of the chemical and energy processes occurring in the low-altitude region of the upper atmosphere is fairly complete, and the important processes have all been treated in considerable detail in published studies. Because of the complexity of the upper atmosphere, however, it has not been possible to apply rigorous observational tests to most of this theoretical work, either to remove uncertainties in the theory or to uncover inadequacies in our understanding. Upper atmosphere processes interrelate many atmospheric parameters and any theory of these processes necessarily involves a number of these parameters. Because atmospheric conditions vary so markedly with position and time, the relevant parameters must be measured simultaneously to test the theory rigorously. To date there have been few opportunities for the coordinated measurement of a sufficient number of related atmospheric parameters, and few of the satellite orbits have been ideal for aeronomic measurements.

The quantities to be measured are:

a. Solar extreme ultraviolet radiation

b. Neutral particle number densities and temperature

c. Ion number densities, temperatures, and species

d. Electron number density and temperature

e. Photoelectron energy spectrum and angular distribution

f. Airglow radiation

The magnetospheric and auroral observation program has the following parts:

a. Measurement of energetic neutrals, protons, other positive ions, and electrons in the energy region from 10 eV to 100 keV over all pitch angles with a fine time resolution

b. Measurement of magnetic field changes in three directions

c. TV observations of auroral forms

d. Three-axis electric field measurements

e. Spectrometric measurements of auroral activity

f. VLF measurements

g. Implatation of auroral ions into pure aluminum foil

Another form of measurement may involve observation of a barium cloud released from a separate cooperative rocket.

To fully utilize the capabilities of the manned observatory, all of the above measurements should be done simultaneously from the same vehicle. The most effective orbits for these kinds of measurements are polar, during which the auroral regions are traversed on each orbit. These orbits may be provided by various shuttle applications missions.

When the spacecraft is approaching the auroral zone, measurement will be made with all appropriate sensors. The desirable reference system for particle measurements is with respect to the direction of the local magnetic field which defines the pitch angle of the precipitated particles. Electric and magnetic fields will be measured simultaneously with the incident flux.

Photometric instruments will be oriented generally downwards to measure the intensities of emissions of the aurora and airglow in the various spectral regions. An image isocon TV camera will be used as an acquisition aid and as a method of recording general morphological data, particularly at low light level emissions.

The optical instrumentation proposed for use in the space physics research laboratory will be suitable for observing the auroral and airglow emissions. The optical instrumentation includes a family of photometers, an interferometer spectrometer, a scanning grating spectrometer, a grazing incidence EUV spectrometer and an image isocon camera. A family of particle detectors completes the instrument array.

Measurement of plasma instabilities, electric fields and wave particle interactions are an essential part of auroral studies; however, some of the instrumentation used is essentially the same as that proposed for FPE 2 and, therefore, will not be described here. The instruments involved are: electric field probe, the VLF antenna, fluxgate magnetometer, and magnetometer search coil.

The instrument descriptions which follow are intended to provide an overall view of equipment and spacecraft interface requirements. The data were obtained from immediately available sources and are believed to be indicative of what will be required. When the scientific experiments are designed in detail, it is expected that many of the instrument descriptions will change; however, the overall scope and impact upon the spacecraft is expected to remain comparable.

1.4.1.2.1 Optical Instrumentation. Three categories of instruments comprise the optical instrumentation for auroral and airglow observations: photometric, spectrometric, and television. The photometric instrumentation is particularly well suited to the auroral observations by virtue of its ability to measure rapidly varying phenomena in several spectral ranges. Three spectrometers will provide an ability to produce finely detailed spectra over the range from 125 Å to 100 μm. Measurements using these instruments will be particularly effective on the more slowly varying airglow phenomena, although they will also be applicable to auroral observations. The use of an image isocon will allow recordings to be made of auroral morphological information. In addition, it will be used as an acquisition aid, allowing the astronaut-scientist to focus attention and point other instrumentation.

1.4.1.2.1.1 Photometric Instrument Cluster. The photometric instrument cluster is conceived to be an assembly of several photometers mounted on a common frame. These photometers would operate in various portions of the spectrum, and they would be pointed generally towards the zenith, towards the nadir, and at other selected fixed angles. The entire assembly would be mounted on gimbals so that any pointing angle could be selected by the experimenter. Several photometer clusters of this type have been flown on satellites during the 1960's[5].

In a typical photometer cluster there will be approximately a dozen different units operating individually and in a complementary manner. The following list presents some of the major photometer parameters which will govern the performance of each unit.

a. Spectral zone

b. Aperture

c. Field of view

d. Effective bandwidth

e. Bandwidth at half of peak transmission

f. Pointing angle

g. Photomultiplier type

h. Threshold sensitivity

i. Upper limit of range

j. Filter materials

An example of a large photometer which is potentially applicable to the auroral/airglow observation program, is the large aperture narrow band 3914 Å photometer shown in Figure 1-2.

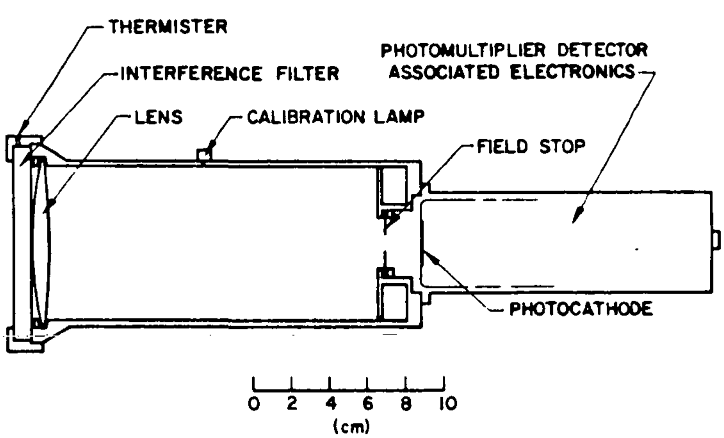


Figure 1-2. Single-Beam Large Aperture 3914 Å Satellite Photometer

1.4.1.2.1.2 Spectrometric Instruments. The space physics research laboratory will include the following spectrometers:

	Instrument	Spectral Range
a.	Interferometer spectrometer	1 to 100 μm
b.	Ebert-Fastie or Czerny-Turner scanning grating spectrometer	0.1 to 1.0 μm
c.	Grazing incidence spectrometer, with secondary emission multiplier	125 Å to 650 Å 250 Å to 1300 Å

These instruments will be mounted on the extendible rails of the airlock to provide complete flexibility with respect to pointing capability.

For purposes of performing altitude scans, the initial starting position will be set by the astronaut using the visible horizon, observed through a small auxiliary eye-piece, as the reference point. However, this setting cannot be used as a fiducial mark, as the altitude of the visible horizon will depend on cloud cover, etc. It is proposed to use the 15 μm radiation from CO_2 to determine the "horizon", as this radiation has been found to have a nearly constant altitude profile for both day and night.

Typical procedures for carrying out an experiment are as follows:

a. The astronaut will select the particular spectrometer to be used, remove it from its storage area, and attach it to appropriate supporting structures in the airlock.

b. The astronaut will attach power cables, etc., to the instrument from the feed-throughs in the chamber.

c. The airlock will then be closed, evacuated to space, and the outside gate opened. The instrument, telescope, etc., which are mounted on rails, will then be moved as one unit outside the spacecraft.

d. The astronaut will turn on the power to the instrument, set the controls (scan rate, etc.) on a control panel, and check that the instrument is working, by observing the scanned spectrum on a storage oscilloscope. When he is satisfied that the instrument is working, the subsequent data will be transferred onto magnetic tape for telemetering to ground. This data will be analyzed by the principal investigators.

Periodically the instruments will need to be calibrated, in situ, by placing calibration lamps in front of the entrance apertures.

a. Infrared Interferometer Spectrometer. The infrared interferometer spectrometer will cover the wavelength range from 1 to 100 μm, at resolutions of about 2 wave numbers at 1 μm, and about 0.5 wave numbers near 100 μm. Three beam splitters will be used; a polymeric film to cover the range 100 to 750 cm^{-1} (100 to 13.5μm) a germanium substrate dielectric film to cover the range 600 to 5000 cm^{-1} (16.5 to 2 μm), a calcium fluoride substrate dielectric film to cover the range 2000 cm^{-1} to 10,000 cm^{-1} (0.5 to 1 μm). Four detectors will be used: a pyroelectric detector to cover the range 1000 to 2500 cm^{-1} (100 to 4 μm); a mercury-cadmium-telluride detector to cover the range 1000 to 2500 cm^{-1} (1 to 4 μm); a lead sulfide detector to cover the range 2500 to 6000 cm^{-1} (4 to 1.6 μm); a germanium detector to cover the range 6000 to 10,000 cm^{-1} (1.6 to 1 μm). The latter three detectors will be cooled by a helium refrigerator unit.

The spectrometer will be a Michelson interferometer, in which the incoming light is devided by a beam splitter, one-half reflected to a fixed mirror, the other by a moving mirror. The complementary beam that returns along the entrance beam will be reflected to the pyroelectric detector which will be fixed in place. The beam that leaves the interferometer at right angles to the entrance beam will be directed to the interchangeable cooled detector (Hg Cd Te, PbS or Ge). The position of the moving mirror will be determined from a reference interferometer which is illuminated by monochromatic light from either a He-Ne laser or an argon lamp. The output from the detectors of the spectrometer will be digitized at intervals controlled by the reference interferometer. Proper alignment of the fixed mirror will be provided by motor driven gears for coarse adjustment and piezo-electric tubes for fine adjustment.

b. Scanning Grating Spectrometer. This spectrometer will be of a 75 cm focal length Ebert-Fastie, or Czerny-Turner configuration. Using magnesium fluoride overcoated optics, it is capable of covering the wavelength range from 0.1 to 1 μm (1000 - 10,000 Å). The resolution attainable depends on the slit widths used: 20 μm slits with a 1200-grooves/mm grating give an ultimate resolution of 0.2 Å. The spectrometer will have the following features:

1. Bilateral adjustable slits, ganged, and coupled to a motor drive plus shaft-encoder for computer programming and setting. Width adjustable from 20 microns to 8 mm, height adjustable up to 50 mm maximum.

2. Kinematic grating mount for easy interchange of gratings. Gratings will re-seat within 1 Å. It is anticipated that three gratings will be used, blazed at 2400 Å, 5000 Å, and 1 μm.

3. Wavelength scan to be achieved by rotation of grating attached to lever mechanism. Lever mechanism piloted by lead-screw attached to stepping motor. Stepping rate controlled from computer or separate controller. Position of scanning mechanism sensed by potentiometer slide and translated by computer into wavelength position.

4. Interchangeable detectors (three separate photomultipliers are envisioned) and electronics.

5. Camera attachment to record spectrum photographically.

The data from these two instruments will be processed through supplied equipment and stored on tape in a digital form.

Both spectrometers will use 16 in. Cassegrain collecting optics.

c. EUV Spectrometer. Rocket and satellite experiments with solar EUV spectrophotometers previously conducted (Solar Ultraviolet Branch at Air Force Cambridge Research Laboratories) have been oriented largely toward aeronomical goals. Therefore, their use in this mission will be an efficient extension of past and current work. Most of this work was carried out with Aerobee-150 rockets equipped with solar-pointed grating monochromators of the focusing type (concave gratings of 2 m radius of curvature and variously chosen grating constants). These were usually designed to scan a substantial portion of the wavelength range from 30 Å to 1300 Å utilizing an exit slit which moved along the Rowland circle, or on occasion designed to operate with nine exit slits located at fixed wavelength positions. Applicable experience also stems from satellite instrumentation on OSO-III (a focusing monochromator similar to the basic rocket-instrument for the range from 250 Å to 1300 Å, with a single exit slit which could be operated either in a mode of scanning or at a fixed-wavelength position selected by ground command) and on OGO-VI (a compact assembly of six grating monochromators of a new non-focusing type, capable of covering the range from 170 Å to 1700 Å with a most desirable degree of overlapping of the six individual sub-ranges).

The solar EUV spectrophotometer recommended here consists of six grating monochromators of the compact non-focusing type described by Bedo and Hinteregger[13] and used in previously documented satellite experiments within the OGO-series.[14,15]

Each of the six monochromators uses grazing incidence (from 78° to 87°, depending on channel) for a planar grating of suitable ruling (600 to 3600 lines/mm depending on channel). The diffracted radiation is analyzed by a special Soller collimator[14] having a length of about 3 cm and a degree of collimation sufficiently modest to be realized readily without undue sacrifice in effective transmission. The wavelength-scanning (or the setting of selected fixed-wavelength positions) is accomplished by rotation of the Soller collimator about an axis perpendicular to the plane of dispersion.

The detection of the diffracted radiation emerging from the collimator is accomplished by a photoelectric detector operated as a counter (Channeltron operated under conditions such as have been used successfully in experiment F-09 and OGO-VI).

The optical portion of the instrument (including the photoelectric detectors and associated amplifiers and HV-supplies) is mounted in an azimuth-elevation gimbal with servo control of the orientation of the instrumental optical entrance axis in the solar direction within a tolerance of about two minutes of arc for both azimuth and elevation. One of these control tolerances could be somewhat relaxed if all six monochromators have planes of dispersion parallel to that control axis which has the cruder tolerance.

1.4.1.2.1.3 Television Instrumentation. Imaging TV systems have been utilized[11] for auroral observation at ground-based stations and on jet aircraft to study auroral microstructure and rapidly varying auroras. They are included in the present program for further work of similar nature, as well for possible use by an astronaut-scientist as an acquisition aid. In this latter mode of usage, the astronaut-scientist will be able to focus attention and point other instrumentation, in response to the low light level observations which the TV system will provide.

Earlier work was based upon the image orthicon tube; the present description assumes the use of an image isocon. The image isocon will provide a greater dynamic range and better low light level signal-to-noise ratios than the image orthicon tube.

Typically, the TV system will use an f 0.75 field lens with a 14° field of view. Exposures of 1/60 second will be recorded on magnetic tape.

1.4.1.2.2 Particle Measurement Instrumentation. A family of electron and proton detectors are required for measurement of number, range, and direction of precipitating particles. These measurements can be made only during periods in which the instruments are present within the particle stream. Such periods are obtainable by use of polar orbit.

In addition, an auroral ion spectrometer will be flown which measures the composition of the incident auroral radiation other than protons and electrons. Table 1-7 presents the ions to be detected and identified and the energy ranges.

A method of detecting incident particles, is the pure aluminum foil experiment. This experiment consists of exposing a thin, high purity target foil for five days on the side of the spacecraft away from the Earth and then bringing the foil back to Earth and analyzing the accumulated nuclides using various high sensitivity techniques that have been developed for analyzing meteorites. On the basis of current theories, the amount of ^{3}He accumulated would vary by a factor of 100 depending on whether auroral particles are of solar wind or ionospheric origin. Thus this experiment would provide some answers about the origin of auroral radiation.

1.4.1.2.3 Ambient Environment Instrumentation. In addition to the sensors described in the preceeding section on optical and particle sensors, the following instrumentation is included to provide a more complete knowledge of the ambient environment. The instruments described below are[6]:

a. Open source mass spectrometer

b. Closed source mass spectrometer

Table 1-6. Particle Detectors on Satellite Instrument Package (1965-A)

Instrument			Threshold (keV)	Direction From Zenith (deg)	Aperture Angle (deg)
Electron Detectors					
Variable Energy Detector	VED	1	0.015 to 10	0	±20
		2	0.015 to 10	180	±20
Angular Distribution Instrument	ADI	1	1	0	±20
		2	1	35	±10
		3	1	55	±10
		4	1	85	±10
Total Energy Detector	TED	1	2	0	±30
		2	9	0	±30
		3	25	0	±30
		4	60	0	±30
		5	9	55	±20
		6	25	55	±10
		7	25	85	±10
Channel Multiplier Magnetic Analyzers ($\Delta E/E = 20\%$)	CMAE	1	1 (a)	55	±5
		2	2 (a)	55	±5
		3	5 (a)	55	±5
		4	12 (a)	55	±5
		5	28 (a)	55	±5
		6	70 (a)	55	±5
		7	Background	55	±5
Proton Detectors					
Variable Energy Detector	VEP	1	0.2 to 10	0	±20
		2	0.2 to 10	55	±20
Total Energy Detector	TEP	1	57	0	±30
		2	57	55	±20
Fixed Threshold Detector	FTP	1	21 (a)	55	±12
		2	38 (a)	55	±12
		3	56 (a)	55	±12
		4	1000	55	±12
Electrostatic Analyzer	ESAP		1 to 15	55	24° ×10°

(a) Central Energy (keV)

Table 1-7. Ion Mass Spectrometer Measurements

Instrument	Ions	Energy Bands
Ion Mass Spectrometer	H^+, H_2^+	1.0-1.6 keV
	$^4He^+$, $^4He^{++}$	1.6-2.5 keV
Aperture Angle: 20°	$^3He^+$, $^3He^{++}$	2.5-4.0 keV
Direction from Zenith:	$^{12}C^+$, $^{14}N^+$	4.0-6.3 keV
0°, 45°, 90°, 180°	$^{16}O^+$	6.3-10.0 keV
		10.0-16 keV
		16-25 keV
		25-40 keV
		40-63 keV
		63-100 keV

c. Neutral gas temperature experiment

d. Ion mass spectrometer

e. Ion trap

Descriptions of the electrostatic probe, electric field probe, flux gate magnetometer, magnetometer search coil, and VLF receiver can be found in Section 2, Plasma Physics.

Because of the primary importance of the neutral composition data, and the complex and difficult nature of the measurements, two independent instruments are required and proposed. An open ion source mass spectrometer, the optimum for measurements of reactive gas species, and an enclosed ion source mass spectrometer, the optimum for the most accurate measurements of nonreactive gas species, will be carefully coordinated in preflight calibrations, simultaneous inflight operations, and data analysis to provide the best attainable neutral composition measurements.

Such a system will be optimized, using the inherent measurement advantage of each instrument with a minimum of compromise. Since an open ion source mass spectrometer can best detect reactive gas species such as atomic oxygen, hydrogen, and nitrogen, before they have undergone significant surface interactions, the best atomic and molecular oxygen measurements are expected to come from the open ion source system. However, inherent in an open-ion source system are problems involving ion source focusing of particles with side energy. Thus, the best data will be obtained when the axis of the spectrometer most closely coincides with the velocity vector. On the other hand, a closed source mass spectrometer, which produces the most precise quantitative measurements of ambient densities for nonreactive species, provides a measure of the sum of the atomic and molecular oxygen (because the atomic oxygen recombines on the surfaces before ionization) over the entire forward looking hemisphere, independent of side energies.

For these reasons the data from the two instruments taken together provide the greatest promise of good measurements of composition in the lower thermosphere.

1.4.1.2.3.1 Open Source Mass Spectrometer. It is proposed to employ a mass spectrometer having an electron bombardment ion source together with a double-focusing magnetic deflection Mattauch-Herzog type mass analysis system. The ion source will be "open" to minimize collisions with the result that active species such as atomic oxygen and atomic hydrogen can be measured. The ion source will be very similar to one flown successfully in a number of rocket flights in recent years. The analyzed ion currents will be measured with electron multipliers and electrometer amplifiers.

Because of the large mass range to be covered (1 to 50 amu), a common trajectory for all ions in magnetic deflection instruments leads either to undesirably high or undesirably low ion accelerating voltages. (For a given trajectory the mass of ions collected is inversely proportional to the ion accelerating voltage.) Therefore, it is proposed to employ two ion collectors as shown in Figure 1-3. One will collect "high" masses, 7 to 56 amu; the other will collect "low" masses, 1 to 8 amu. This arrangement has the additional advantage that one can examine two different constituents of the atmosphere at the same time, e.g. He and N_2 at masses 4 and 28 respectively.

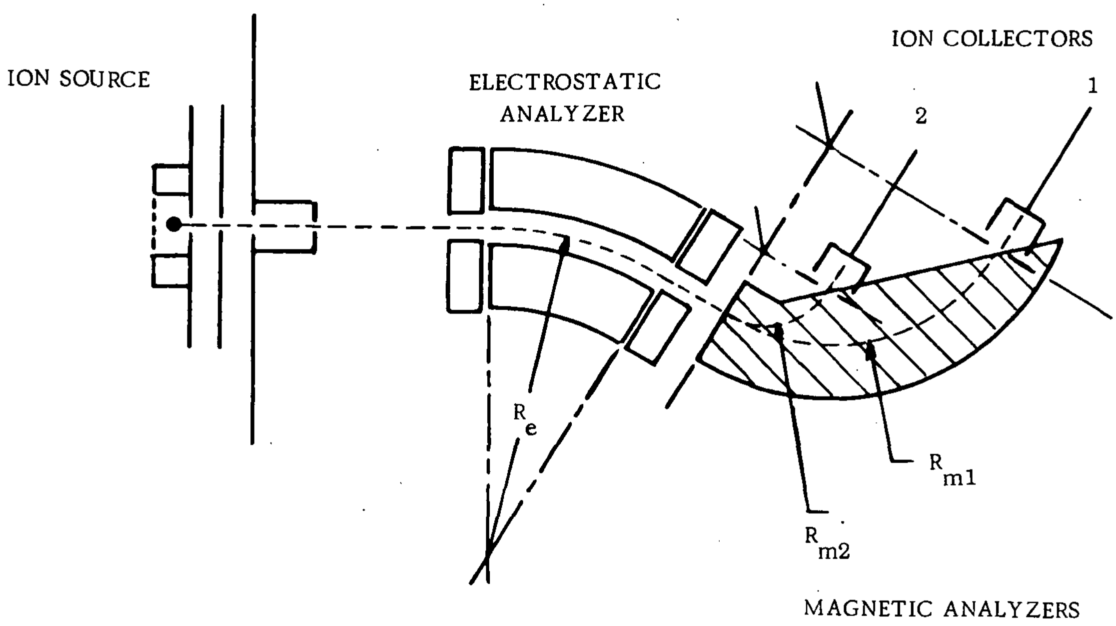


Figure 1-3. Double-Focusing Mass Spectrometer, Mattauch-Herzog Geometry

In another mode of operation, one will be able to scan an entire spectrum. Such a mode would permit an occasional look at other mass positions to see how the impurities are behaving, to look for other possible rate constituents.

1.4.1.2.3.2 Closed Source Mass Spectrometer. The closed source mass spectrometer will be a direct extension of the OGO-6 instrument now operating in orbit. The sensor will be a quadrupole mass spectrometer employing a spherical ante-chamber, which interfaces with the ambient atmosphere through a knife-edged orifice. The sensor will consist of a dual filament ion source, a quadrupole analyzer utilizing hyperbolic rods, and an off-axis electron multiplier. The spectrometer will have a mass range of 1 to 46 with better than one mass unit resolution at all masses, and the measurement system will have a dynamic range of approximately 10^8. The electronic system will consist of an electrode power supply and emission regulator, rf oscillator, detector, and logic subsystems. A block diagram of the system is shown in Figure 1-4.

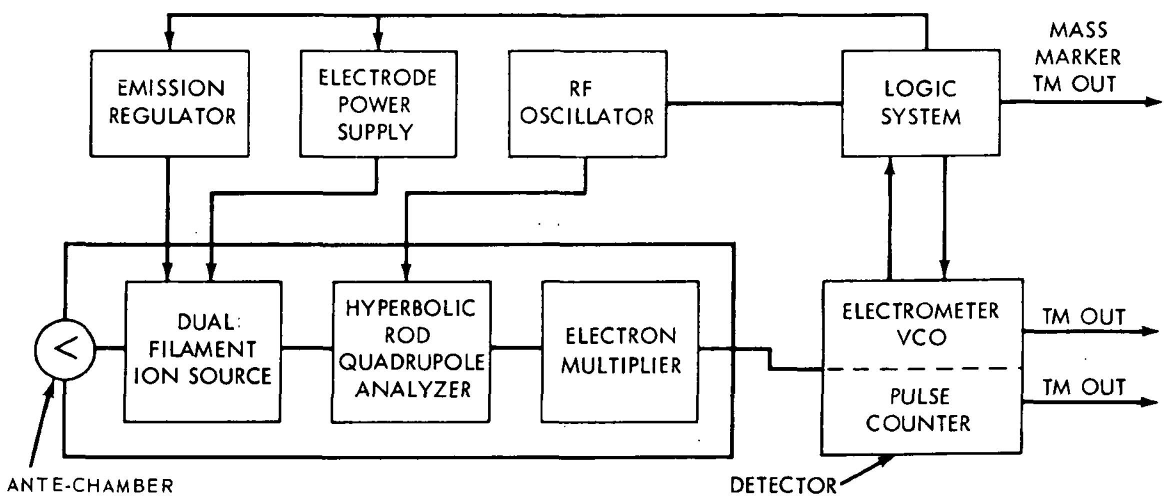


Figure 1-4. Closed Ion Source Neutral Mass Spectrometer

The electrode power supply and emission regulator power the electron guns and ion focusing lens systems. The rf oscillator provides combinations of ac voltages and frequencies to effect mass selection in the analyzer. The detector system measures the output of the multiplier over a dynamic range of 10^6, utilizing a pulse counter and an integrating current measurement operating in parallel (the absolute accuracy of the detector system is thus essentially independent of the gain of the electron multiplier). An additional 10^2 in overall dynamic range is achieved by automatically desensitizing the ion source at the high densities which may be encountered. The logic system accepts commands and clock pulses from the spacecraft and controls the experiment configuration.

Several operating modes will be incorporated in the experiment. These modes will include: (1) sequential stepping to preselected masses, (2) sweeping entire and/or selected segments of the mass range, and (3) fixed-tuning to a single mass or a few selected masses for extended periods. A command matrix will permit selection of one of several (approximately 15) configurations made up of combinations of the modes described, and operation will be correlated with the operation of the open ion source mass spectrometer. This format provides the capability to periodically obtain concentrated measurements of trace atmospheric constituents, to check for proper tuning of the instrument, and to monitor possible contaminent constituent levels.

1.4.1.2.3.3 Neutral Atmosphere Temperature Experiment. The purpose of the experiment is to provide direct, in-situ measurements of the kinetic temperatures of the thermosphere neutral atmosphere. To do this, the instantaneous concentration of atmospheric molecular nitrogen in a specially designed small spherical chamber, carefully orificed to the atmosphere, will be measured and analyzed. The spherical chamber will be mounted on a rotating arm and will exhibit an internal density variation that has been demonstrated through flight test to be predictable by kinetic theory. Analysis of the variation of the N_2 concentration in the chamber, by a variety of techniques, and with knowledge of the satellite velocity and motion, permits a determination of the local temperature of molecular nitrogen, without consideration of scale height. A measurement of the ambient nitrogen density is also obtained.

A special mode of experiment operation provides an alternative approach to kinetic temperature measurement. The particle flow upstream of the orificed spherical chamber is physically modified, and the temperature dependent effects of the modification upon the transverse velocity of the particles are then observed.

A spherical antechamber with a knife-edged orifice facing normal to the spin axis will be mounted on the satellite. The chamber will be sealed in vacuum prior to launch and opened to the atmosphere after the satellite is in orbit. A sample of the spherical chamber gas will be passed to a small dual filament ion source which will produce an ion beam proportional to the chamber density. The ion beam will be directed into a quadrupole analyzer which will pass ions with an m/e ratio of 28 to a multiplier where individual ions are converted to "packets" of electrons. The "packets" are counted at the multiplier output thus providing a digital output proportional to the chamber mass 28 density. The aforementioned components comprise the sensor. The antechamber, redundant dual filament ion source, and multiplier are developed and have been flown on rockets and a satellite. The quadrupole analyzer is a miniaturized version of the OGO-6 instrument.

The electronic system is comprised of a multiplier, counter, data processor, power supplies, and logic subsystem. These are shown in the block diagram in Figure 1-5. The detector amplifies the multiplier output pulses and feeds them to the data processor. The data processor operates on the detector output to provide three digital output signals, N_i, $\dot{N}_i$, and $\ddot{N}_i$, where N_i is the inside density of N and $\dot{N}_i$ and $\ddot{N}_i$ are the first and second derivatives with respect to the angle between the normal of the orifice plane and the gauge velocity vector.

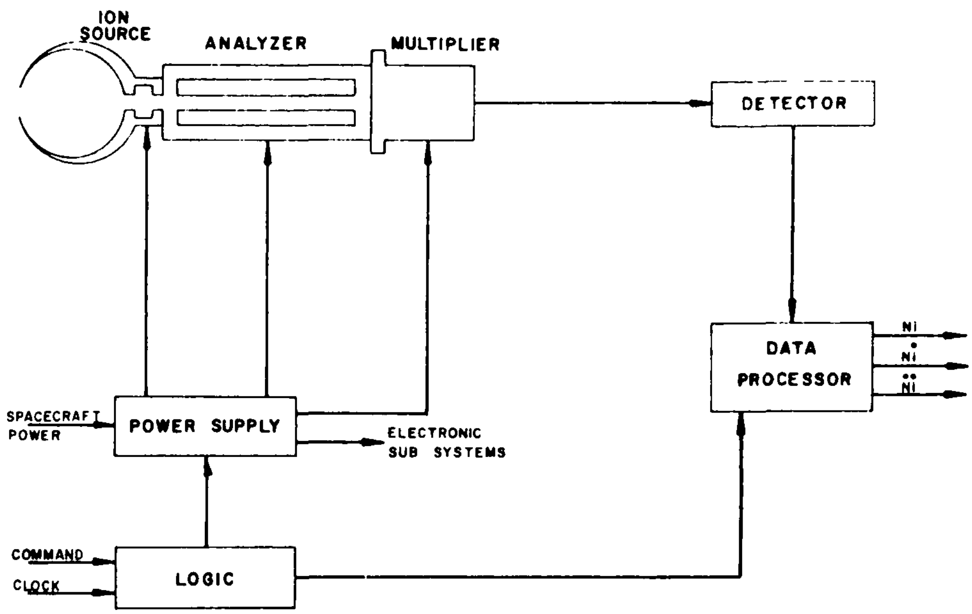


Figure 1-5. Neutral Atmosphere Temperature Experiment

Power supplies provide the electrode potentials for the ion source, analyzer and multiplier and the voltages required to operate the electronic system. The logic accepts commands and clock pulses from the spacecraft to control and configure the experiment.

The electronic system is comprised of subsystem designs that have been used previously by the experimenters on rockets, San Marco C, and OGO-6.

1.4.1.2.3.4 Positive Ion Mass Spectrometer. The Bennett radio frequency spectrometer, a direct descendent of the instruments flown successfully on OGO's 1, 2, 3, 4, 6 and Explorer 32 (AE-B), will make continuous high resolution measurements of thermal positive ions between 1 and 36 amu, sweeping the mass range in five seconds, and detecting all ions of concentration 10 to 2×10^6 ions/cm^3. On command, the instrument will switch to a "high mass only" mode which permits doubling the spatial resolution of perigee data by continuously sweeping the mass range above 4 amu with a period of 2.5 seconds. The spectrometer should be mounted in the forward-looking section of the spacecraft.

The proposed Bennett rf ion mass spectrometer is an instrument of high resolution and sensitivity, capable of measuring the composition and concentration of positive ions in the atmosphere over a wide range of ion mass and ambient density. The experiment group has successfully flown several versions of this instrument on a number of sounding rockets and satellites, including OGO's 1, 2, 3, 4, 6 and Explorer 32.

Briefly, the spectrometer operates as follows. Ambient atmospheric ions are drawn into the instrument by a negative orifice field and are accelerated down the axis of the spectrometer by a slowly varying "sweep" potential. For each ion mass there is a value of the sweep which accelerates the ion to the instrument's "resonant velocity". Those ions, which traverse the tube at the resonant velocity, gain energy from the rf field in the spectrometer's three analyzer sections, and are then able to pass through a retarding potential field and reach the collector at the end of the tube. An electrometer converts this collector current to a voltage which is then processed by an amplifier having a dynamic range corresponding to currents from 1×10^{-13} to 2×10^{-8} amperes. The amplifier output is compressed into a single analog telemetry channel, and this, along with an analog monitor of the sweep potential, constitutes the primary data output of the experiment. Additional processing of the amplifier output permits the primary experiment data to also be read out in the form of two digital words, one indicating the current and the other the sweep potential measured for each ionic constituent.

Figure 1-6 is an outline drawing of the instrument.

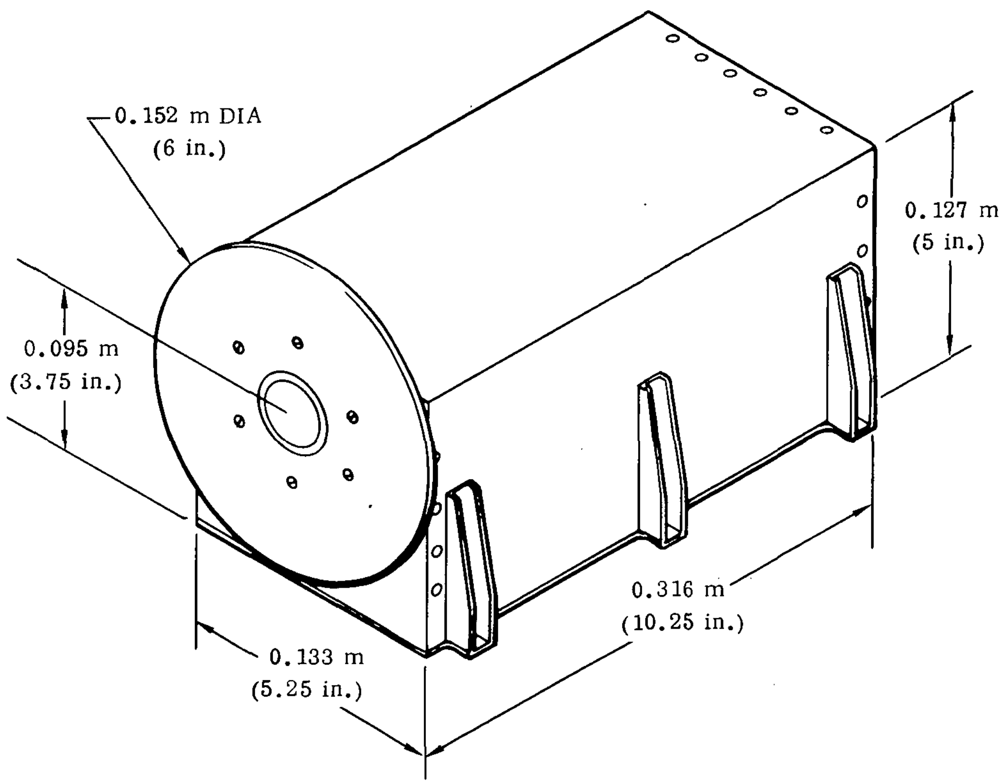


Figure 1-6. Positive Ion Mass Spectrometer

1.4.1.2.3.5 Planar Ion Trap. The ion trap is an improved version of the instrument recently launched on OGO-VI. It has also been undergoing development and testing in a series of Javelin rockets. The measured parameters are:

a. Ion temperature

b. Ion concentration (including small scale fractional changes > 10^{-3})

c. Ion composition

d. Suprathermal electron fluxes

e. Electron temperature

The sensor head consists of an eight cm diameter cylinder with a two-cm diameter aperture through which charged particles pass before striking a solid collector. The path between the aperture and collector is electrically segmented by a series of grids whose potentials are controlled by the main electronics box. The physical arrangement of these elements is shown in Figure 1-7. In addition to amplifying the signal from the collector and feeding it to the telemeter, the main electronic box also selects the mode of operation of the instrument, either by internal programming or by command.

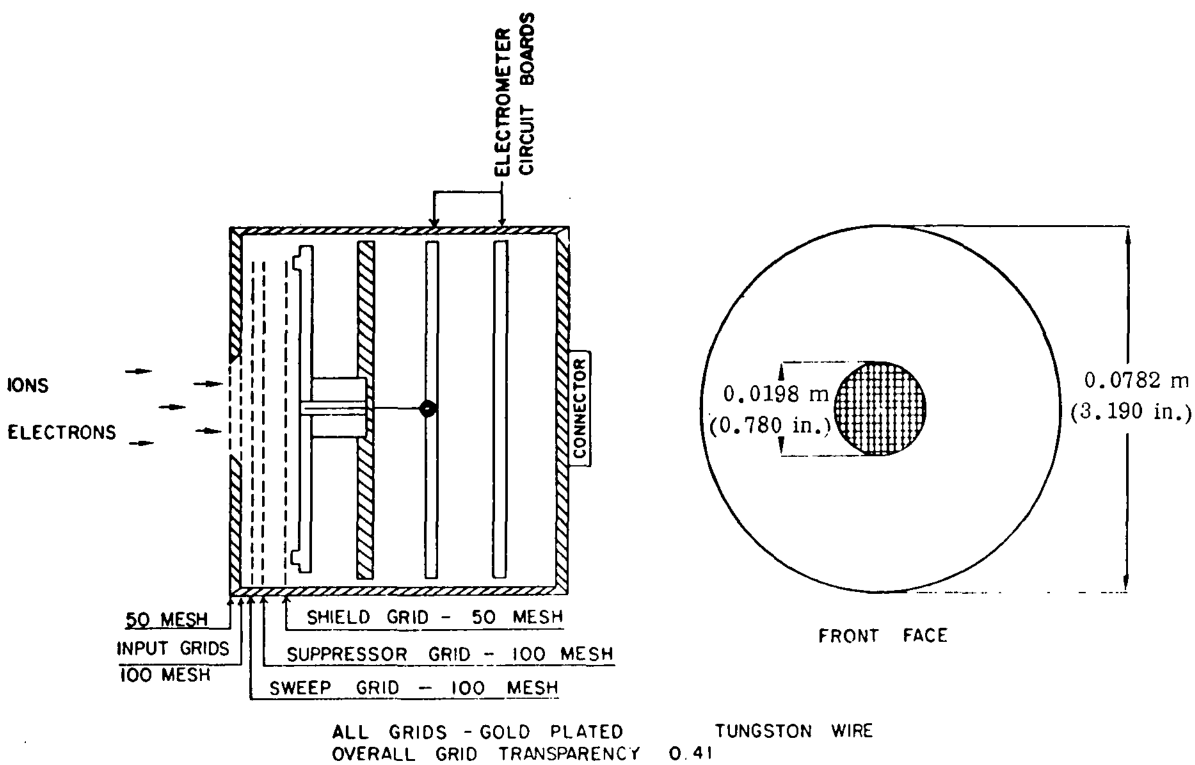


Figure 1-7. Ion Trap Head

The electrometer is a linear automatic-ranging device with a maximum sensitivity of approximately 3×10^{-11} amp/volt. Adjacent ranges differ by $\sqrt{10}$ in sensitivity and there are eight different ranges; thus, ion concentrations can be detected from approximately 5 cm^{-3} to 5×10^{6} cm^{-3}. When the instrument is facing away from the sun, suprathermal electron fluxes of greater than 10^{6} cm^{-2} sec^{-1}, at the collector, can be detected.

1.4.1.3 Observation/Measurement Program. The observations and measurements to be made, are the following:

a. Optical measurements of auroras and airglow

b. Auroral imaging

c. Particle measurements including energy and angular distribution of electrons and protons

d. Ambient environment measurements

Table 1-8 presents a list of candidate experiments which can be performed using the optical portion of the SPRL. For the auroral optical observations, the spacecraft may either be in the auroral zone or in an orbit which affords an oblique view of the aurora.

Auroral zones: The 100% isochasms*, northern and southern, have a mean angular radius about the geomagnetic pole of approximately 23° and an angular width of approximately ±2°. The frequency of auroral visibility decreases with increasing distance from the auroral zone more rapidly on the side towards the equator than on the side towards the pole.

Targets to be viewed for the auroral observation programs are in the latitude regions from ±45° to ±90°. Polar orbits will be particularly effective for these zones, and will allow simultaneous use of particle sensors and optical sensors since the satellite will pass through the incident particle stream. During orbits of inclinations of the order of magnitude of 45° to 60° and greater, the optical instrumentation will be able to obtain data with an oblique field of view, and the particle sensors will seldom be usable.

Among the zones of particular interest for airglow observations, are the twilight areas, both at dawn and evening.

The spectral lines and ranges of interest for photometric measurement are listed in Table 1-9.

Typical energy ranges of particles which will be measured are listed in Table 1-6.

1.4.1.4 Interface, Support and Performance Requirements. A summary of requirements of the Atmospheric and Magnetospheric Science observation program is shown in Table 1-2. During the early portions of the observation program, it is recommended that the instruments be operated more or less continuously for a period of four days. This initial data run will provide basic information from one complete survey of the Earth from which subsequent observations will be planned and scheduled. Those instruments primarily oriented towards the magnetospheric science would operate in the polar zones.

*Isochasm - A line of equal frequency of visibility of aurora given as the percentage of nights at each place on which, at some time during the hours of darkness, an aurora can be seen in some part of the sky if the clouds do not interfere.

Table 1-8. Optical Facility - Candidate Observation/Measurement Programs

	Infrared - 0.7 to 500 μm (7000 to 5,000,000 Å)	Visible - 0.35 to 0.7 μm (3500 to 7000 Å)	Ultraviolet - 0.11 to 0.35 μm (1100 to 3500 Å)	Extreme Ultraviolet - 0.025 to 0.125 μm (250 to 1250 Å)
Instruments Needed	a. 0.203 m (8 in.) telescope cooled to 80° K or below b. Larger telescope, but uncooled c. Three interferometer spectrometers to cover range 0.7 to 500 μm, the range 0.7 to 10 μm being at high resolution detectors capable of being cooled to 2° K. d. Radiometers	a. Ebert-Fastie scanning spectrometer, 0.5 Å resolution b. 0.203 m (8 in.) telescope, 0.1 milliradian resolution c. Trace element Ma, Li, Mg in visible range	a. Ebert-Fastie spectrometer, using photon counting technique, with a resolution of 0.5 Å b. 0.203 m (8 in.) telescope with coated optics	No one instrument can be considered for this wavelength region, nor can a simple telescope be used because of poor reflectivity of the surfaces
Areas of Research	a. Study of aerosal layers (8 to 12 μm) b. Atomic oxygen altitude profiles (63 and 147 μm) c. Molecular oxygen profiles (1 to 15 μm) d. Detection of air pollution (1 to 15 μm) e. Altitude profiles of CO_2, O_3, and OH (1 to 15 μm) f. Auroral phenomena (1.5 to 150 μm) g. Humidity and temperature profiles of lower atmosphere (1 to 15 μm) h. Planetary spectra i. Spectra of bright stars, nebulae, zodiacal light j. Cometary physics k. Cloud physics l. Solar spectrum (entire disk) (20 to 300 μm)	a. Airglow continuum b. Study of aerosol layers c. Auroral phenomena d. Red arcs, imagery and spectra e. Meteorology f. Planetary spectra g. Atmospheric emissions	a. Altitude profiles of N_2, O_2, NO, etc. b. Backscatter of solar radiation from Earth to study ozone and noctiluscent clouds c. Solar spectrum, 1100 to 3500 Å, both relative and absolute measurements d. Cometary physics e. Planetary physics f. Spectra of nebulae and galaxies g. Proton aurora imagery in Lyman Alpha h. Dayglow, 1100 to 2000 Å	a. Horizon dayglow b. Nightglow c. High resolution, absolute photometry of solar emission for the whole disk

Table 1-9. Photometric Spectral Lines and Ranges of Interest

Atmospheric Species	Experiment
N_2	Observations of Lyman-Birge Hopfield bands in Aurora. 1200 to 2400 Å.
N_2^+	Observations of N_2^+ first negative system at 3914 and 4278 Å.
N	Observations of emission lines at 1200 Å and possibly at 1493 Å.
H	Observations of emission line at 1216 Å.
O_2	Absorption of solar ultraviolet radiation between 1100 and 1950 Å. In the wavelength interval 1750 to 1950 Å, the data could be used to give atmospheric temperature profiles between 70 and 100 km.
O_3	a. Absorption of solar ultraviolet radiation between 2500 and 3000 Å for daytime profile measurements. b. Absorption of ultraviolet airglow emission for nightime profile measurements.
O	Observation of emission lines at 1304, 1356, 5577 and 6300 Å. Emission at 1304 and 1356 Å is especially interesting in the equatorial regions.
NO	Observation of fluorescence in the gamma band system as a result of excitation by solar radiation, 2050 to 2800 Å.
OH	Observation of night- and day-glow of vibrationally excited hydroxyl. Intensity yields composition information. Band structure yields temperature. Bands can be observed in the spectral range of about 0.6 to 4 μm.
$O_2 a'\Delta g$	Observations of emission bands at 1.27 and 1.58 μm.
$O_2 b'\Sigma$	Observation of Atmospheric Bands in emission at 8640 and 7600 Å.
$O_2 A^3\Sigma$	Observation of Herzberg Bands in emission, 2500 to 3800 Å.
Na	Observation of resonance fluorescence at 5890 and 5896 Å. This measurement can also be used to determine the atmospheric temperature.
He	Observation of resonance fluorescence at 584 Å.

1.4.1.5 Potential Role of Man. The most important role of the astronaut-physicist will be the selection of observations to be run after the initial data run. In addition he will exercise judgment with respect to selecting specific times and zones in which to take data by observing spontaneous auroral and airglow activity, and most important, he will be able to select appropriate instruments for use.

1.4.1.6 Available Background Data.

Reference No.	Reference
1.	William T. Roberts, Memorandum to W. T. Carey, General Guidelines for Blue Book Rewrite of FPE's 5.6, 5.7, 5.8, 5.12, 5.27, Physics Experiments, July 17, 1970.
2.	Candidate Experiment Program for Manned Space Stations, September 15, 1969, NASA NHB7150.XX.
3.	Earth Orbital Experiments Program and Requirements Study, Task 4 Report, June, 1970, TRW Systems draft report to McDonnell-Douglas Astronautics Co.
4.	R. D. Hudson and A. E. Potter, Atmospheric Science Experiment Facility - Outline of Proposed Experiment for Space Station, Space Physics Division, NASA/MSC.
5.	J. E. Evans, R. G. Johnson, and R. E. Meyerott, Autoral Input - Output Experiment, Final Technical Report No. 8-79-68-1 for period 1 April 1961 to 31 January 1968; 31 January 1968; Lockheed Palo Alto Research Laboratory.
6.	A Coordinated Study of the Aeronomy of the Atmosphere, August 1969. (A NASA team proposal by L. H. Brace, NASA/GSFC et al.)
7.	Auroral Zone Rocket Experiment, February 1966, TRW Systems Proposal.
8.	William Liller, Space Astrophysics, 1961, McGraw-Hill Book Company, Inc.
9.	Donald P. LeGalley and Alan Rosen, Space Physics, 1964 John Wiley & Sons, Inc.
10.	Billy M. McCormac, Aurora and Airglow, 1967, Reinhold Publishing Corporation.
11.	T. N. Davis, "Television Observation of Auroras", Atmospheric Emissions, edited by Billy M. McCormac and Anders Omholt, Van Nostrand Reinhold Co., 1969.

Reference No.	Reference
12.	W.I. Axford, "On the Origin of the Radiation Belt and Auroral Primary Ions", Particles and Fields in the Magnetosphere, edited by B.M. McCormac, D. Reidel Publishing Co., Dortrecht-Holland, 1970.
13.	Jap. J. Appl. Phys. 4, Suppl. I, p. 473, 1965.
14.	H. E. Hinteregger and D.E. Bedo, Instrumentation Manual, Experiment 20, OGO-C and -D, February 1966.
15.	D.E. Bedo, Instrumentation Manual, Experiment 9, OGO-F, January 1969.

1.4.2 COMETARY PHYSICS - GASEOUS RELEASE OF NH_3 AND ICN[16]

1.4.2.1 Scientific Objectives. In the field of comet physics, one of the most significant and interesting problems is the determination of the physical mechanism or mechanisms responsible for the production of the observed radicals and ions. There has been produced, to date, very convincing evidence supporting a resonance fluorescence mechanism by solar electromagnetic radiation for most of the comet observed molecular and atomic emission, but there the success apparently stops. The problems of the mechanisms of dissociation and ionization of most of the stable parent molecules and product fragments remain unsolved.

In spite of a host of attempts to theoretically or experimentally ascribe these phenomena to orthodox theories of simple interactions between the molecules of the cometary atmosphere and the solar corpuscular or electromagnetic fields, little progress has been made. Most of these attempts fail by orders of magnitude to produce sufficient material quickly enough to be responsible for the cometary observations.

It is in this area of mechanisms that it may be possible to gain some insight with the proposed gaseous releases. This experiment will emphasize observations from which insight pertaining to the physical and chemical mechanisms controlling the cometary environment will be gained.

Gaseous release experiments represent a subset of the larger category of chemical release experiments. (See Section 4, Physics and Chemistry Laboratory.) One of the major goals of chemical release experiments is to investigate that branch of space chemistry which includes the ionization, dissociation, and reaction of molecules in the atmospheres of the planets of the solar system, in interstellar space, as well as in cometary bodies. The Sun is a major source of excitation of molecules in atmospheres and in comets. The total solar flux including the extreme ultraviolet, X-rays and higher energy radiation cannot be fully simulated in the laboratory. These experiments will therefore duplicate the natural conditions as closely as possible by using the unattenuated solar flux at orbital heights. Wall effects, which can de-excite molecules, cause radical and ion recombination will be eliminated. These effects cause serious problems in the laboratory when exact data on excitation rates and chemical reaction is necessary.

Chemical releases of NH_3 (ammonia) and iodine cyanide are proposed to study the fluorescence of the evolved radicals NH_2 and CN which occur in cometary emissions. Relatively small amounts (1 to 3 moles) will be released from appropriate canisters engineered to minimize the formation of particles whose Mie scattering would mask the fluorescence. A spectrometer will measure the radiation at various vibration transitions. From this measurement a comparison with cometary spectra will be made and an evaluation of the plausibility of photolysis as the causative mechanism will be completed. Such an experiment will also help to evaluate the fluorescent effect of contaminants on spacecraft sensors.

The fluorescence experiments on the NH_2 and CN radicals are selected because they are prominent radicals in cometary spectra and they are also considered (perhaps optimally) accessible to spectroscopic examination. In the case of NH_2 a release of ammonia, NH_3, of hydrazine, N_2H_4 is suggested. In this case the release serves as a test of the photolysis hypothesis and a check on the fluorescence spectrum in an integrated fashion. In effect such an experiment checks the partial results of existing laboratory studies, gives a total picture and provides a comparison with the release cometary spectra.

The CN fluorescence will be studied through the release of ICN which has a rapid rate of dissociation in the solar ultraviolet. This experiment then will only simulate the cometary CN fluorescence since ICN is not a cometary molecule. The use of ICN is predicated on the advantageous signal it will give.

The nature of the formation of the radicals observed in comet spectra remains in doubt. At present the general conclusion is that ions observed are created by as yet some unknown magnetohydrodynamic process of which Wilks[17] has made an analysis. Jackson and Donn[18] have concluded that photolysis is capable of accounting for the distribution and emission characteristics of the radical behavior in comets and Wurm[19] still believes that to explain the presence of radicals in comets and their kinematic behavior, it is necessary to invoke some process other than photolysis.

1.4.2.2 Description. The space physics research laboratory will provide the facility for (1) chemical release and (2) spectrometric measurement. The presence of an astronaut - physicist onboard will allow some data evaluation and varied emphasis on different portions of the spectrum is likely to result.

1.4.2.2.1 Chemical Release. Mie particle scattering is to be avoided (by releasing material in the vapor phase) since masking of the desired flourescence would result. It seems that any release of bulk materials, either liquid or solid, would tend to produce many particles. In particular, in the case of NH_3, there is already evidence that such particles of a particularly effective scattering size (0.1 to 1.0) have been created. The crux of the problem is to assure release of the material in the vapor phase. Starting with an initial vapor phase the only process producing particulate matter will be homogeneous nucleation during the expansion. Such a process is collision dependent and in the rapidly expanding gas tends to be minimal as far as the creation of large particles is concerned. The theory of Grobman and Buffalano[20] has indicated that for gas diffusing through the walls of a spaceship 10 cm thick, particles no bigger than 150 Å are formed. Moreover, nozzle[21] and wind tunnel experiments[22] have shown that such entities as are created are small and may be termed polymers rather than particles. They are in all cases smaller than 150 Å and hence their contribution to light scattering is such that they do not constitute a significant interference to the visible fluorescence. In particular, this is so because as demonstrated in Milne and Greene's[21] molecular beam experiments even these small polymers were present in relatively small percentages. Consequently, the release schemes proposed employ only gas whose behavior is controlled to minimize the presence of particles. For specificity only two gases will be analyzed, ammonia (NH_3) and iodine cyanide (ICN).

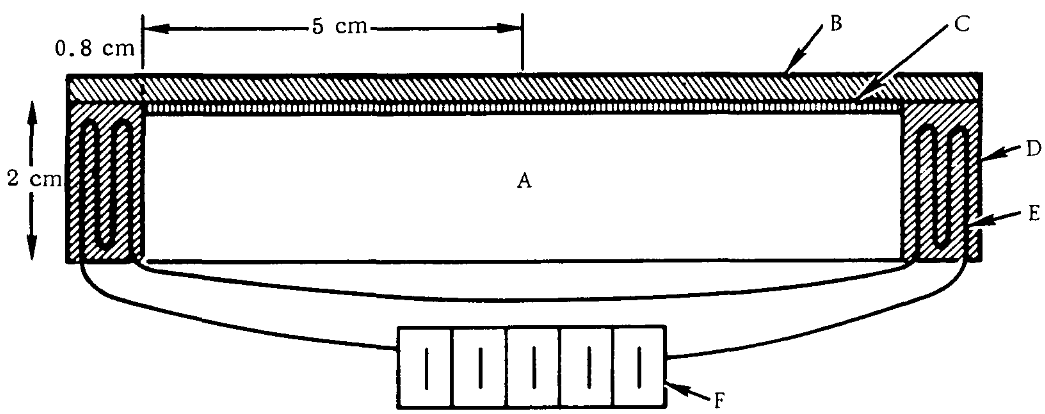
1.4.2.2.2 <u>Release of NH_3</u>. The thermochemical and physical properties of ammonia are well established. Ammonia has a large vapor pressure such that at room temperature its vapor pressure is of the order of ten atmospheres (at 289.4°K and 299.4°K the vapor pressure is 5804.2 and 7956.6 mm of Hg respectively). A large enough volume will be used such that for a mass of NH_3 employed the saturation pressure at the canister temperature is not reached. Because the pressure within the canister is lower than the saturation pressure, the gas and liquid phases cannot coexist.

The final design of the canister payload will depend upon the space and weight available. Below are given some of the payload characteristics for a payload in the 0.0454 - 0.454 kg (0.1 to 1.0 lb) range. The actual mass used will depend upon engineering tradeoff. A nominal canister pressure of ten atmospheres will be selected as a compromise between the desire to achieve a high mass density per unit volume and at the same time to minimize the pressure. At ten atmospheres a sphere of 0.20 m radius can hold a mass of 0.045 kg (0.1 lb). For 4.54 kg (10 lb) a sphere of 0.28 m radius is required (1.8 ft in diameter).

A sudden release mechanism (solenoid operated) will open the sphere to vacuum. Because the NH_3 is initially in the gaseous state it will first have to undergo considerable oversaturation before nucleation can occur: This must be followed by growth which can only occur by collisions. Because the gas is rapidly being diluted through expansion, growth can not be rapid. Consequently it is concluded that only particles less than 1000 Å in radius will occur. It is considered that for practical realization of this experiment that vacuum testing in the laboratory of this technique of release should occur before any satellite experimentation.

1.4.2.2.3 Release of ICN. ICN exists as a solid at room temperatures but begins to sublime rapidly at temperatures of around 330.8° K when its vapor pressure reaches 10 mm. The release concept is depicted in Figure 1-8. It envisions the rapid sublimation of the solid ICN in a period of between 100 and 1000 seconds caused by the heating induced by a coil energized from a special power-pack of batteries. The gas passes to the exterior through an array of small diameter tubes. At present only rather general calculations can be presented because the requisite thermochemical properties of ICN are not available in the literature, viz. International Critical Table, JANAF Thermochemical Tables, etc. Consequently, because such data as the heat of vaporization are missing only a reasonable estimate of the energetics can be made.

The design pictured in Figure 1-8 is for a mass of 0.153 kg or one mole of ICN. Equivalent devices for different masses may be analogously constructed. It is a relatively small device and requires around 2.26 to 6.8 kg (5 to 15 pounds) of batteries.



A = INNER VOLUME FOR ESCAPE OF ICN GAS
B = COVER
C = MULTIPLE-TUBE COLLIMATOR
D = IODINE CYANIDE
E = HEATER
F = BATTERY PACK

Figure 1-8. Schematic of Canister Design for Dispersing One Mode Of ICN Vapor

1.4.2.2.4 Spectrometric Measurements. Emissions from the gaseous release are expected to be visible for several hundred seconds, and hence are amenable to measurement by spectrometic means. The Ebert-Fastie spectrometer (described in Section 1.4.1.2) is suitable for use in this experiment.

1.4.2.3 Observation/Measurement Program. The gaseous release process and the spectrometric measurements will require approximately 30 minutes each. Set-up and calibration will require of the order of one hour. The complete experiment requires of the order of 90 minutes to perform for each run involving release of both ICN and NH_3. It is recommended that these runs be repeated several times in order to gain confidence in the measurements. Use of the spectrometer provides data over a very wide spectral range; however, certain regions are of particular interest. These are listed below:

2150 Å to 3000 Å	-	ICN photodissociation continuum
3850 Å to 3884 Å	-	CN violet system
3200 Å	-	NH
2250 Å	-	NH_3
2700 Å	-	N_2H_4
5000 Å to 6000 Å	-	$NH_{2\alpha}$
2000 Å to 3000 Å	-	N_2H_4
3050 Å	-	OH

1.4.2.4 Interface, Support, and Performance Requirements. Table 1-3 presents the experiment-peculiar interface support requirements.

1.4.2.5 Potential Role of Man. One of the most important roles to be played by man in this experiment is the perusal of the spectral data obtained from the first experiment run. By applying his knowledge of the experiment objectives and expected results, he will be able to identify particular spectral regions of interest, and expand appropriate time and amplitude scales on the scanning spectrometer to obtain more detailed data on subsequent runs.

1.4.2.6 Available Background Data.

Reference No.	Reference
16.	J. Pressman, J. Myers, P. Lilienfield, of GCA Corp., Bedford, Massachusetts, Definition of Experimental Studies for Determining Gaseous and Particulate Cloud Environment of Manned Spacecraft and Applications to Cometary Physics, Final Report Contract No. NASw-1745, May 1970.
17.	H.K. Wilks, Planet, Space Science, 15, 1407-1418 (1967).
18.	W.M. Jackson, and B.Donn, Icarus, 8, 270-280 (1968).

Reference No.	Reference
19.	M. Wurm, Ammonia Release Experiments in the High Atmosphere and the Dissociation Processes in Comets, (to be published).
20.	J.D. Cobine, Gaseous Conductors, Dover, New York, p. 209 (1958).
21.	T.A. Milne, and F.T. Green, J. Chem. Phys., 4, 16 November 1967, p. 4095.
22.	H. Thomann, The Physics of Fluids, 9, 5 May 1966.
23.	William T. Roberts, General Guidelines for Blue Book Rewrite of FPE's 5.6, 5.7, 5.8, 5.12, 5.27, Physics Experiments, Memorandum to W. T. Carey, July 17, 1970.
24.	Candidate Experiment Program for Manned Space Stations, September 15, 1969, NASA NHB7150.XX.
25.	Earth Orbital Experiments Program and Requirements Study, Task 4 Report, TRW Systems draft report to McDonnell-Douglas Astronautics Co., June 1970.

1.4.3 METEOROID SCIENCE

1.4.3.1 Scientific Objective. The space physics research laboratory will provide a facility for the performance of experiments in meteoroid science. Data obtained from these experiments will provide information on the fundamental characteristics of the universe, and for use in more effective design of future spacecraft. The recommended experiments fall into five basic categories:

a. Recovery experiments

b. Composition analysis

c. Small meteoroid experiments

d. Optical detection of larger meteoroids - mass and velocity

e. Thick penetration experiments

With the exception of meteorites which have been altered by their flight through the atmosphere, we have had a close look at only one extraterrestrial object - the Moon. Whether meteoroids originate in the asteroid belts or are remnants of comets, they are composed of material in a primordial state. They are at least of as much importance in our understanding of cosmological processes as the Moon. Hence, experiments to determine their basic properties - origin, composition, physical properties, interplanetary distribution, size distribution, etc. - are of significance and justified from a strictly scientific point of view.

Although data has been obtained on some meteoroid parameters, there is a lack of data with respect to specific measurement of meteoroid mass, velocity, composition, trajectory, and origin. It is probable that spacecraft structures, meteoroid bumpers, radiators, etc., may be over or under designed from the viewpoint of providing adequate protection for minimum weight. The Space Station program is expected to provide a relatively clean environment in which to run varied experiments over substantial periods of time with a minimum of complexity. Data will be obtained and analyzed, in situ, and samples and specimens can be returned to Earth for extensive ground based examination.

Each experiment is typical of the class of experiment being considered.

1.4.3.2 Descriptions

1.4.3.2.1 Recovery Experiment

1.4.3.2.1.1 Scientific or Technical Objective. To measure the flux of near-earth meteoroids having masses between about 10^{-17} and 10^{-11} kg. This will provide verification of the Pegasus 38 μm (0.0015 in.) thick aluminum penetration and laboratory extrapolated data, and extend this data into the small particle region which causes erosion of the spacecraft skin and optical surfaces.

1.4.3.2.1.2 Description. The experiment hardware consists of ten panels hinged together by torsion springs. The springs are preloaded to fold the panels into a packaged configuration. Each panel contains 12 specially prepared impact plates which may be of various materials, for example, glass with highly polished surfaces. The experiment is deployed by opening the panels in the external space environment.

1.4.3.2.1.3 Observation/Measurement Program. The plates will be exposed to the space environment for at least one year to expose the plates throughout one orbit of the Earth about the Sun. A decision to run the experiment longer can be made, depending upon the results of astronaut inspection. When the mission is complete, the experiment is folded, retrieved, and returned to the Earth for analysis.

1.4.3.2.1.4 Interface, Support and Performance Requirements. The experiment must be deployed and the spacecraft oriented such that it is not looking directly at the Earth and in an area where the exposed surfaces are not shadowed by any portion of the spacecraft or attachment to the spacecraft. It should be deployed where impingement from RCS jets is a minimum.

The packaged configuration dimensions are 0.152 m $\times$ 0.406 m $\times$ 0.076 m (6 $\times$ 16 $\times$ 3 in.). The deployed configuration dimensions are 1.52 m $\times$ 0.406 m $\times$ 0.076 m (60 $\times$ 16 $\times$ 3 in.). The weight is 5.9 kg (13 lb).

Attitude stabilization requirements are ±10 degrees. The orbit altitude should be at least 278×10^3 m (150 n.mi.). There are no inclination requirements.

1.4.3.2.1.5 Potential Role of Man. The design will be considerably simplified if deployment and retrieval is performed manually. Inspection of the plates to determine if the experiment should be continued or terminated can be performed.

1.4.3.2.2 Cosmic Dust Analyzer Experiment

1.4.3.2.2.1 Scientific Objectives. The Cosmic Dust Analyzer (CDA) experiment is intended to perform in situ compositional analyses of individual cosmic dust particles with very small masses. Elemental constituents in the mass number range 1 to 60 will be identified with a resolution of ±1 amu or better and the relative abundance of such constituents will be measured. Although the laboratory version of the CDA has been successfully tested at a limiting mass sensitivity of 10^{-19} to 10^{-20} kg, the limiting sensitivity of the flight version will be slightly less than 10^{-15} kg. This results in a simpler instrument; in addition, it is currently felt that the fraction of cosmic dust particles with masses less than 10^{-15} kg is extremely small.

1.4.3.2.2.2 Description. The CDA uses the impact ionization effect. When an incoming particle strikes a solid target, a microplasma is formed containing ions of the particle constituents and of the known target materials. An electric field between the target and a grid adjacent thereto extracts these ions and accelerates them toward an ion collector one meter away. The ions drift to the collector in a field-free region, where they separate in time according to mass number. Therefore, the time of flight of any ion group to the collector can be measured directly by using as a $t = 0$ reference, a signal produced at the target at the instant of the original impact. The time of flight is readily converted to mass number. Relative abundances are measured by comparing the peak amplitudes of the particle-constituent ion group signals to the ion group amplitudes for the target constituents.

The target plate with associated grids and electronics is mounted on the exterior of the spacecraft and is 0.305 m (1 ft) in diameter. The ion collector with its electronics is located one meter away from the target on extendable booms that are deployed in orbit. One boom supports a cable which returns the collector signals to the spacecraft. The data collection unit is essentially a single-sweep oscilloscope with trace-recording camera mounted in the interior of the spacecraft; access to this unit by spacecraft personnel need only be infrequent. Since the data are recorded oscillographically, there is no digital telemetry requirement.

In operation, the trace-recording camera shutter is open. When an impact occurs, the target signal starts the oscilloscope sweep. The ion collector signal containing data for all ion groups present appears on the trace and is photographed. At the conclusion of the single sweep, the film is electrically advanced to the next frame, after which the sweep is rearmed. An indicator (audible, visual, or both) warns when the film cartridge is expended, at which time the cartridge is changed by spacecraft personnel.

1.4.3.2.2.3 Observation Program. Each particle impact represents one datum which is acquired instantaneously, the corresponding data record being one frame of the exposed oscillogram film. It is preferred that data be acquired from several directions of view, but this is not an absolute requirement. The estimated number of meteoroid impacts on a surface with masses 10^{-15} kg or greater is 3.16×10^{-5} per square meter per second; on a 0.305 m (1 ft) diameter target, this implies 0.2 impacts per day or 5 days per impact. Assuming a 1:1 ratio of accidental to real events, a recorded event occurs once per 2.5 days, which corresponds to approximately 73 recorded events in a mission of six months duration.

1.4.3.2.2.4 Interface, Support, and Performance Requirements. See Section 1.4.3.2.2.6. The following should also be noted:

a. There is no digital data communication requirement.

b. An unrestricted field of view is required. A variable pointing direction is preferable; minimum pointing requirements with a nonvariable direction are that the direction be parallel to, rather than perpendicular to, the ecliptic plane and that the direction not be toward the Earth.

c. Data return consists of return of the exposed oscillogram film cartridges. These may be returned as available via shuttle for immediate analysis, or else their return may await the conclusion of the mission.

d. The oscillographic data recording unit is to be located within the pressurized quarters of the spacecraft.

1.4.3.2.2.5 Potential Role of Man. As previously stated, the minimum human role in the CDA experiment consists of periodic replacement of film cartridges. Since 73 events are expected in a six-month mission, the use of 36- or 40-exposure cartridges reduces the expected number of changes to two. This may be expanded by using smaller cartridges, which has the advantage of making some of the data available (via shuttle) for immediate analysis before the end of the mission. The film-changing operation requires no special skills.

1.4.3.2.2.6 Experiment Requirements.

a. Weight - 4.54 kg (10 lb)

b. Volume

1. Target/ion collector (external to spacecraft) - 2.82 (10^{-2}) m^3 (1 ft^3) stowed, 8.5 (10^{-2}) m^3 (3 ft^3) deployed

2. Data recorder (internal) - 1.42 (10^{-2}) m^3 (0.5 ft^3)

c. Envelope

1. Target/ion collector - 0.305 m (1 ft) dia × 0.396 m (1.3 ft) stowed, 0.305 m (1 ft) dia × 1.01 m (3.3 ft) deployed

2. Data recorder - 0.305 m (1 ft) × 0.305 m (1 ft) × 0.153 (0.5 ft)

d. Power - 10 watts

e. Crew Skills - No special skills

f. Environmental

1. Target/ion collector - magnetic fields <1 gauss

2. Data recorder - in crew habitable environment

g. Time Limits - None; estimated time to collect one datum - five days

h. Data Requirements - Return of exposed film cartriges (two or more), via shuttle as available or at end of mission

i. Pointing

1. Preferred - variable, with direction readout

2. Minimum - fixed parallel to ecliptic plane, not toward Earth

1.4.3.2.2.7 Available Background Data. The CDA is fully described in the following documents:

TRW Systems Report No. 10735-6001-R0-00, prepared for NASA/MSC, April 1970

TRW systems Proposal No. 16657-6001-P0-00, submitted to NASA/MSC, June 1970.

1.4.3.2.3 Small Meteoroid Mass and Velocity

1.4.3.2.3.1 Scientific Objective. This experiment will provide a very accurate measurement of the velocity vector of impacting meteoroids, from which the orbit may be determined. In addition, an estimate of the kinetic energy and momentum may be inferred from measurements of impact ionization and microphone detection. Post-recovery analysis will allow composition analysis of the residual meteoroid material.

1.4.3.2.3.2 Description. The experiment is shown schematically in Figure 1-9. It consists of a front film-grid sensor array and a rear film-grid sensor array spaced 5 cm apart (film plane to film plane), and an acoustical impact plate upon which the rear film is mounted.

The performance of the sensors depends upon two basic, measurable phenomena which occur when a hypervelocity particle impacts upon a surface: the formation of an ionized plasma and a transfer of momentum.

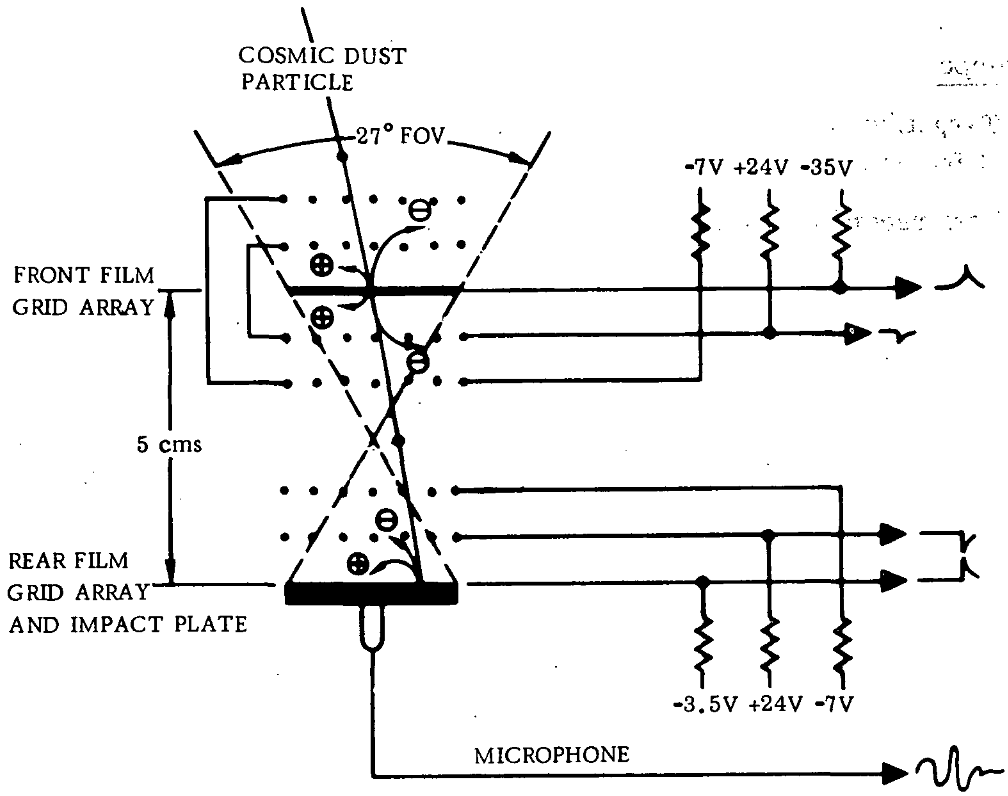


Figure 1-9. Schematic Diagram Of The Basic Cosmic Dust Sensor

In conjunction with the following explanation of the operation of the experiment, refer to Figure 1-9 and consider three probable cosmic dust particle types: (1) a high-energy hypervolicty particle (>1.0 erg); (2) a low-energy hypervelocity particle (>10^{-10} kg).

As a high-energy hypervelocity particle enters the front film sensor, it yields some of its kinetic energy toward the generation of ionized plasma at the front film ("A" film). Electrons from the plasma are collected on the positively biased grid (+24 V) producing a negative-going pulse which is amplified as shown. The ions from the plasma are collected on the negatively biased film (-3.5 V) producing a positive-going pulse which is amplified as shown and pulse height analyzed as a measure of the particle's kinetic energy. As the particle continues on its path, it yields its remaining energy at the rear sensor film ("B" film) and plate, generating a second set of plasma pulses and an acoustical pulse (if the particle's momentum is sufficient). A peak pulse height analysis is performed on the acoustical sensor output as a measure of the particle's remaining momentum.

As a low-energy hypervelocity particle enters the front sensor, it yields all of its kinetic energy at the "A" film. A pulse height analysis is performed on the positive output signal as a measure of the particle's kinetic energy. A high-energy hypervelocity particle may erroneously be registered as a low-energy hypervelocity particle if, because of its angle of entry into the experiment, it fails to impact on the "B" film.

As a relatively large, high-velocity particle enters the experiment, it may pass through the front and rear film sensor arrays without generating a detectable ionized plasma, but still impart a measurable impulse to the acoustical sensor.

An electronic "clock" registers the time of flight (TOF) of the particle as the time lapse between positive pulses ("A" film and "B" film output signals) which is used to derive the particle's speed.

The TOF sensor, as described, is one of 256 similar sensors (including 31 control sensors) which comprise that portion of the experiment which measures particle speed and direction. Figure 1-10 is an exploded schematic view of the overall experiment, showing that four vertical film strips are crossed by four horizontal grid strips to form 16 front and 16 rear film sensor arrays (each 2.5 cm square) creating 256 possible combinations. Each grid strip and film strip connects to a separate output amplifier. The output signals from these amplifiers are used to determine the segment in which an impact occurred. Thus, knowing which front film-grid segment was penetrated and which rear film-grid segment was affected by an impact, one can determine the direction of the incoming particle with respect to the sensor axis and, eventually, to the spacecraft attitude. A solar aspect sensor in the spacecraft is used to determine the sun-spacecraft angle at the time of an impact. This readout is initiated by an impact event involving the "A" film and/or the "B" film and/or the microphone. Thus the angle of the incoming particle with respect to the Sun can readily be determined.

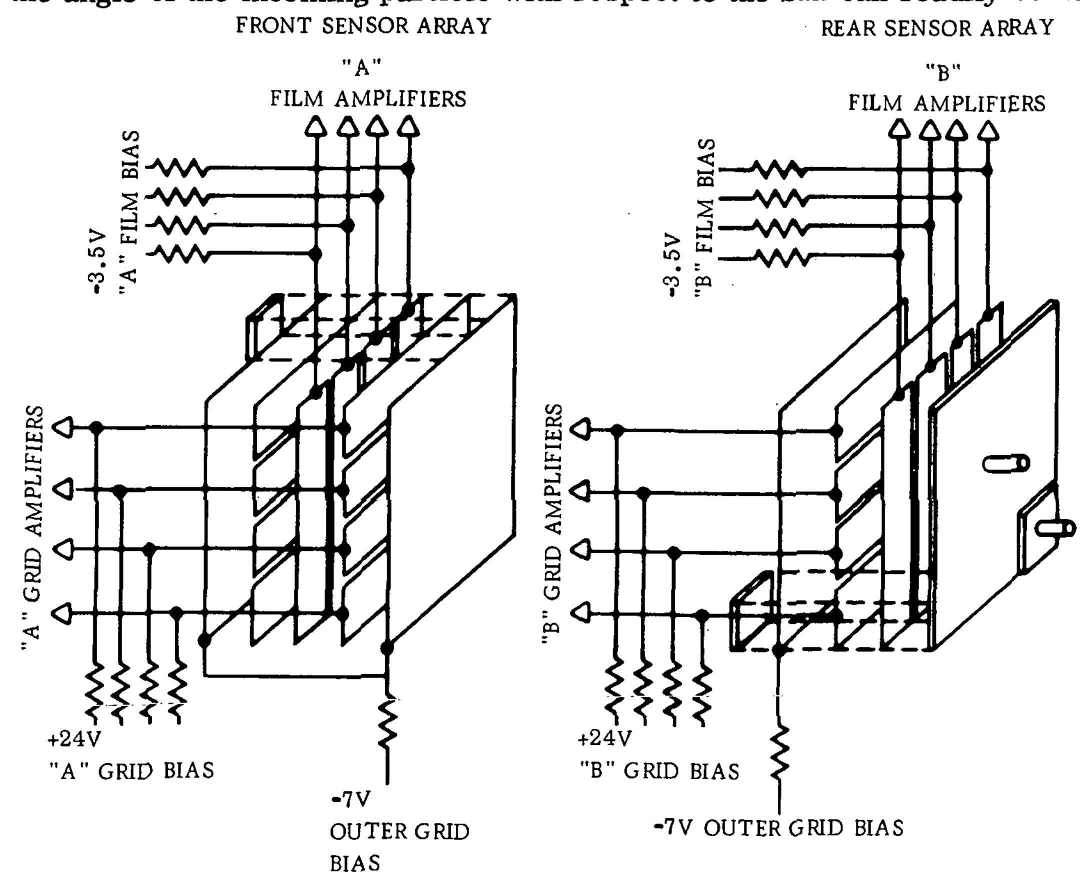


Figure 1-10. Schematic Diagrams of Sensor Array

Each of the four vertical films of the front sensor array as shown in Figure 1-10 is a composite of eight layers. Ideally, a thin copper foil (500 Å) would be used alone for the vertical strips of the front sensor array,* but is obviously too fragile and subject to corrosion. Therefore, a nickel grid, the Parylene** substrate, and the Parylene encapsulation are used as supports and anticorrosion covering for the metal film deposits. The aluminum layers serve only as fabrication aids during the preparation of the composite film to reflect the intense heat generated by copper evaporation upon the Parylene substrate.

Each of the rear sensor array film strips is a 60 μm molybdenum sheet cemented to a quartz acoustical sensor plate. The optical transparency of each of the grids (including support mesh) is 98.8%.

The maximum field of view of the experiment is that of the front film array and is square with a half-angle of 60° yielding a 4.5 sr field. The minimum angular resolution of each TOF detector is ±27°.

The data are displayed as 48 bits on four 6-bit words. This is accomplished by alternately displaying the data in two formats, as the "O" frame and "1" frame.

The first bit in each frame identifies the frame. The next 8 bits in the "O" frame identify the "A" film strip and "A" grid column which was affected by a cosmic dust particle impact. Bits 10 and 11 record the number of events measured by the control microphone. Six bits are assigned to time of flight (TOF) for projectiles in the velocity range 2 to 72 km/sec, which corresponds to a TOF range of 2.5×10^{-5} -7×10^{-7} sec. Any "A" film event initiates the start of a 4-MHz "clock" which is stopped by either a "B" film event or a filled register of 63 bits. A solar aspect counter utilizes the next six bits of frame "O". This device starts its count upon each revolution of the spacecraft (one rps) at a time when the Sun sensor sees the Sun. The last bit in frame "O" provides an experiment parity check.

The next 8 bits following frame ID in frame "1" are used for "B" film strip and "B" grid column identification for the rear sensor array. A single bit is used to indicate signal noise which may have occurred during PHA of any "A" film event or microphone event. Bits 11 and 12 of frame "1" register the total number of main microphone events. "A" film PHA and microphone PHA are registered on the next bits as shown. The remaining 4 bits are assigned to the display of accumulated "A" film bits. All the data on both formats remain and are repetitively displayed until an event occurs which involves the "A" film, the "B" film, or the microphones.

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* Target materials such as copper, molybdenum, tantalum, etc. have been found by experiment, to enhance the formation of plasma from hypervelocity impacts.

** A patented product of the Union Carbide Corporation.

1.4.3.2.3.3 Interface and Support Requirements. The preceding description is for a single unit. For the proposed space station experiment, the use of three identical units is recommended. Each sensor is 0.1 × 0.1 m (4 × 4 in.) square, and when mounted with the electronics, each package has the dimensions of 0.2 × 0.2 × 0.2 m (8 × 8 × 8 in.) and a weight of 2.04 kg (4.5 lb). The power consumption of each unit is 0.5 W.

1.4.3.2.3.4 Available Background Data.

Otto E. Berg and F. Frank Richardson, "The Pioneer 8 Cosmic Dust Experiment," Review of Scientific Instruments, Vol. 40, No. 10, 1333-1337, October 1969.

1.4.3.2.4 Optical Detection Meteoroid Experiment.

1.4.3.2.4.1 Scientific Objectives. The Optical Detection Meteoroid Experiment (ODME) is intended to detect meteoroid masses in the range of 10^{-12} kg to 10^{-6} kg. The instrument provides the velocity components of the meteoroid, and thus with knowledge of the instrument's location and orientation in space, the complete orbit of the body in the solar system.

1.4.3.2.4.2 Description. The ODME uses reflected or scattered solar radiation from a moving particle for detection, size and velocity determination. The passage of the body is measured by three individual non-imaging optical subsystems. The entrance and exit times of the particles through each of the three fields of view are all that are required to completely determine the range and three velocity components of the body. From the measured range, and separately measured amplitude of the signal, the albedo "cross-section" equal to the reflectivity (assumed constant) times the illuminated cross-sectional area is determined.

The three optical subsystems are aligned to give three parallel cones in space. Each subsystem consists of field optics (lenses, mirrors or combinations) and a photomultiplier tube. The data is processed by the ODME electronics and returned through the spacecraft's digital telemetry.

1.4.3.2.4.3 Observation Program. The event rate expected per day is given in the following table relative to particle mass.

Events Per Day	Mass (kg)
100	10^{-12}
20	10^{-11}
5	10^{-10}
1	10^{-9}
0.2	10^{-8}
0.05	10^{-7}

There are several restrictions which the orbit and the instrument orientation impose on the amount of optical observing time available. Observing time is lost when:

a. The Sun enters the field of view

b. The lighted Earth enters the field of view

c. The instrument is viewing the dark side of the Earth

d. The instrument is eclipsed by the Earth

1.4.3.2.4.4 Interface, Support and Performance Requirements. The pointing accuracy of one to two degrees needed by ODME is quite modest. Misalignment of the optical subsystems is not critical as long as the misalignment is known. Alignment calibrations can be performed using stars. Since the orbit cannot be freely selected, a gimbal pointing system will be necessary. Since the pointing accuracy requirement is modest, a simple gimbal system may be used. The scanning sequence can be precomputed and stored in the central computer.

The total weight of the package, including optics shields, electronics and pointing control, should not exceed 34 kg (75 lb). Total power requirements for the instument should not exceed 7.5 W average.

The instrument will require 264 telemetry bits for each event.

1.4.3.2.4.5 Available Background Data

General Electric Proposal No. N-11130-1 to NASA/LRC

General Electric Proposal No. GE N-11194

1.4.3.2.5 Thick Material Meteoroid Penetration Experiment

1.4.3.2.5.1 Scientific Objective. The objective of this experiment is to narrow the limits of uncertainty of the near Earth meteoroid flux. Present estimates (NASA SP-8013) of the penetration flux to be expected for thick spacecraft walls can be several orders of magnitude in error.

1.4.3.2.5.2 Descriptions. The experiment chosen to be typical of this category uses approximately 45.4 m^2 (500 ft^2) of pressure cell panels, typically mounted on the forward and aft skirt areas of the vehicle. Two thicknesses of pressure cell penetration detectors will be used, 685 μm (0.027 in.), and 203 μm (0.008 in.). The use of thicker materials is appropriate to more effectively simulate actual spacecraft materials. The actual thickness used should be as thick as possible consistent with a reasonable rate of event occurrence and acceptable area and weight limits. The 685 μm (0.027 in.) thick detector panels each consist of a 685 μm (0.027 in.) thick stainless steel sheet welded to a 107 μm (0.042 in.) thick stainless steel sheet around the periphery and in a square field spot pattern. The interior of the two sheets is then pressure expanded to form the pressure cavity. Diaphragm actuated pressure switches are mounted in each detector for puncture detection.

The 203 μm (0.008 in.) thick detector panels each consist of a 203 μm (0.008 in.) stainless steel sheet and a 406 μm (0.016 in.) thick stainless steel sheet welded together essentially as described for the 685 μm (0.027 in.) detector panels. Each 203 μm (0.008 in.) thick detector also has diaphragm actuated pressure switches. The use of gas flow monitoring techniques would give additional data on size and multiplicity of punctures.

The meteoroid environment uncertainties that could be obtained by flying the 685 μm (0.027 in.) thick pressure cell detectors on the workshop are illustrated in Figure 1-11.

1.4.3.2.5.3 Observation Program. During the entire period of space station operation, the detector panels will be interrogated periodically to count the number of penetrations which have taken place since mission inception. The experiment data system is a simple matrix scan unit which will, upon command, scan serially the status of all the detector pressure switches and feed the data directly into a remote multiplexer unit. The experiment will draw no power except when commanded in a scan mode. The experiment data transmission requirements are very low and the time for scan commands is not critical, thus allowing the data transmission to be performed during off-peak periods.

1.4.3.2.5.4 Interface, Support, and Performance Requirements. Table 1-10 presents the weight and dimension characteristics of this experiment. The electrical power requirements are less than 5 W.

Table 1-10. Meteoroid Experiment Weight and Dimensions

Detectors	Number	Size, meters (inches)	Weight, (pounds)	kg
203 μm (8 mil) steel	52	0.155 × 0.389 (6.1 × 15.3)	(61)	27.7
685 μm (27 mil) steel	71	0.64 × 1.12 (25.2 × 44.0)	(1,651)	750
Detectors			(1,712)	778
Mounting Hardware and Fairing			(148)	68
Wiring			(41)	18.6
Data Systems			(8)	3.6
		Total	(1,909)	868

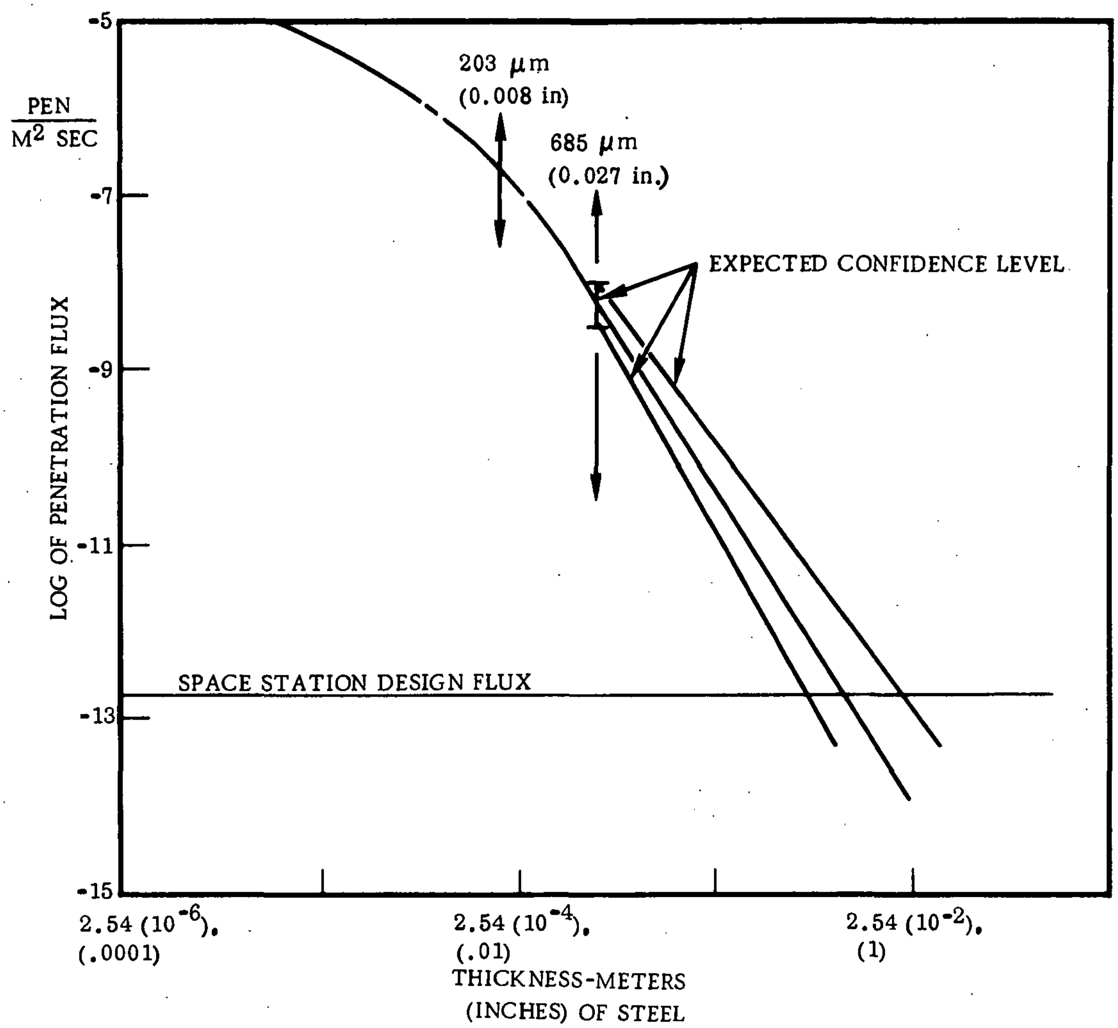


Figure 1-11. Expected Confidence Level In Environmental Uncertainty

1.4.4 SMALL ASTRONOMY TELESCOPE

1.4.4.1 Scientific Objective. The scientific objective of the Small Astronomy Telescope is to complement and supplement the astronomical investigations to be conducted with its larger cousins, such as the Advanced Astronomy Module or the UV Stellar Survey Module of the Space Station.

There are a variety of investigations which can be conducted with a moderate size telescope as efficiently as or even more efficiently than with a large telescope. The reason is partly because there exists much work that does not require a great photon gathering capacity. Also, a smaller aperture telescope, designed to perform specific tasks, can be a more efficient instrument for these specific tasks. It may be recalled that since completion of the famed 5.08 m (200-in.) telescope at Palomar Mountain, numerous smaller telescopes have been and are still being constructed as vital tools for astronomers. In analogy to the smaller ground-based telescopes, the small Space Station telescopes are intended to make space observations more easily accessible to the interested astronomers.

1.4.4.2 Experiment Descriptions

1.4.4.2.1 Ultraviolet Telescope Spectrometer

1.4.4.2.1.1 Scientific Objective. Investigation of unique emission features, such as Mg II doublet at 2795 and 2802 Å, or C IV and Si IV emission lines in the far UV, is planned for this instrument. The Mg II investigation applies to questions of the structure of stellar atmospheres, particularly chromospheres, and envelopes, and also possibly to stellar wind and magnetic field. The C IV and Si IV studies will provide vital information on the rate of mass loss from stars. Also, a high resolution survey of absorption lines due to interstellar and circumstellar matter is of importance. While a coarse scanning mode may be satisfactory for investigations of the interstellar Lyman-alpha absorption, a fine scanning mode will be needed for observing narrow absorption lines such as those due to interstellar molecular hydrogen. A comparison of the interstellar Mg II and Mg I absorptions at 2795 + 2802 and 2851 in the spectra of early B stars may provide a powerful technique for investigating the interstellar electron density and temperature.

1.4.4.2.1.2 Description. The telescope spectrometer is intended to be a versatile, high-resolution system for analysis of stellar ultraviolet spectra. A representative optical layout is presented in Figure 1-12 and critical parameters are provided in Table 1-11.

The Ebert-Fastie grating mount is chosen because of its versatility and high resolution capability. This instrument described here is an adaptation of the scanning grating spectrometer described in Section 1.4.1.2. Two 2160 grooves/mm gratings, blazed for different wavelengths, are mounted back to back with provisions for changing to other gratings. The instrument may be operated in first, second, or third order for differing dispersions, at the discretion of the investigator. A filter wheel order sorter (not shown) is located in front of the detector. The resolution, to within the 0.1 Å limit, is controlled by adjustable entrance and exit slits (not shown) and the selected spectral order. The spectrum is scanned by step rotation of the grating. The performance parameters stated in Table 1-11 are well within the current state-of-the-art and are feasible with the instrument design presented here. Good performance can be extended down to wavelengths near 1000 Å with modification to spectrometer layout, employing current techniques. The light baffles extending beyond the secondary will be collapsible for storage in the space physics module and in the airlock.

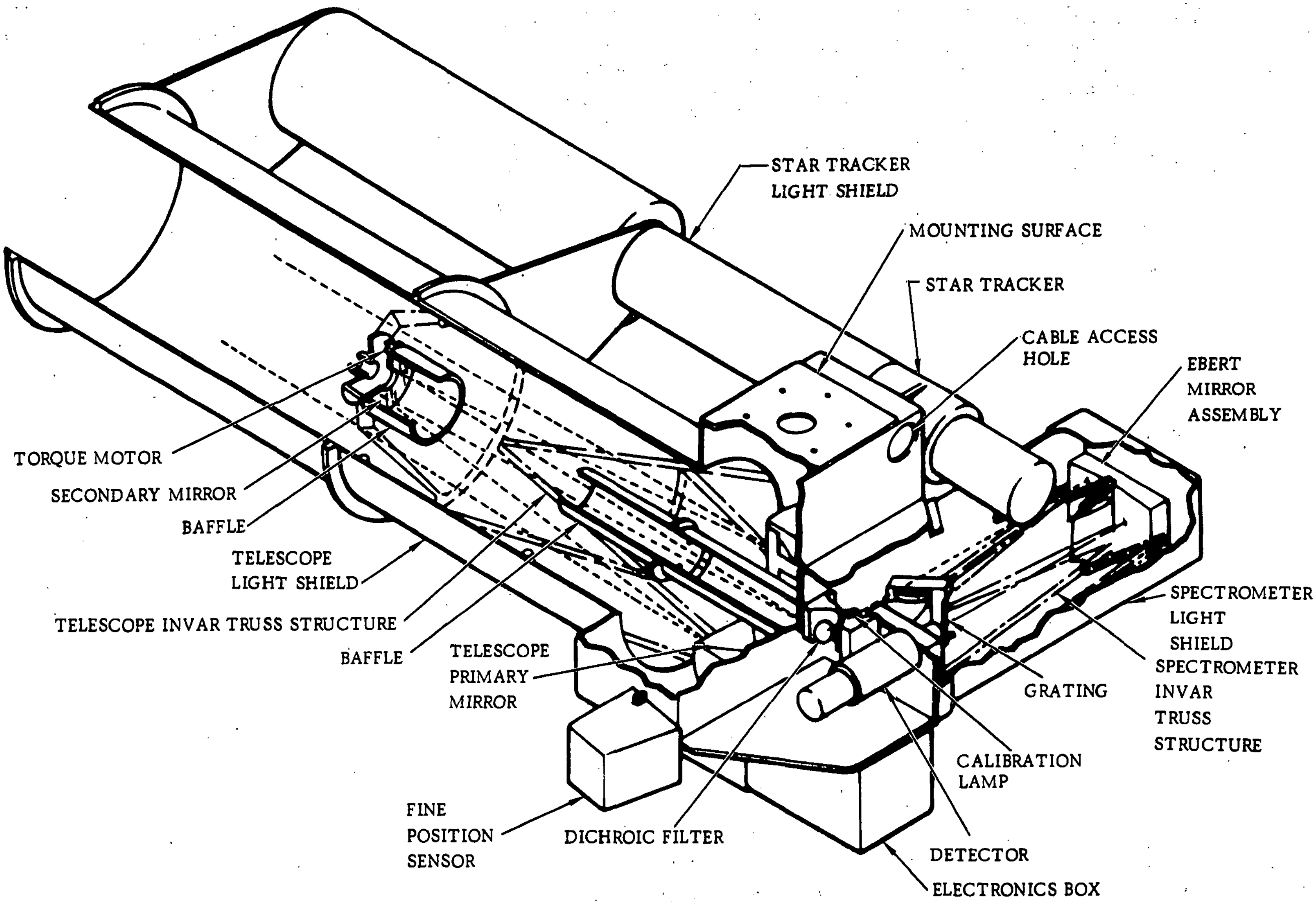


Figure 1-12. Ultraviolet Telescope Spectrometer

Table 1-11. Ultraviolet Telescope Spectrometer Characteristics

Spectrometer	Grating/optics configuration	Ebert-Fastie
	Ebert mirror focal length	0.5 m
	Grating ruling frequency	2160 grooves/mm
	Blaze	Grating interchange provided
	Dispersion	2.2 Å/mm (3rd order)
	Resolution	To 0.1 Å
	Slits	Adjustable 50 to 20 μm
	Spectral range	1200 Å - 3000 Å
	Spectral order	1, 2, or 3
	Order sorting	Filter wheel at detector
Telescope	Optical configuration	Tilted aplanatic Cassegrain
	Primary diameter	40 cm
	System f No.	7.5
	Net light collecting area	940 cm^2
	Angular resolution	2 arcsec
	Field of view of spectrometer entrance stop	±14 arcsec
Detector	Type	Sealed end on photomultiplier
	Cathode material	Cesium antimonide
	Quantum efficiency	>0.1 from 1200 Å - 3000 Å
	Window	Lithium flouride with magnesium flouride overcoat
	Gain	10^6

Pointing of the instrument is achieved with a coaxial star tracker. Fine pointing is achieved with a servo-controlled secondary. At the telescope focus, a dichroic filter directs the visible light to the fine pointing system, which controls the telescope secondary, and directs the ultraviolet to the spectrometer. The tracking error for fifth magnitude stars is 1.6 arcsec rms.

1.4.4.2.1.3 Role of Man. In addition to deploying the instrument and monitoring its operation, an astronaut can change gratings, giving greater versatility to the instrument and allowing examination of used gratings for contamination and deterioration.

1.4.4.2.2 Space Image Tube Optical System

1.4.4.2.2.1 Scientific Objective. The understanding of the composition and distribution of matter is diffuse nebulae and galaxies and of the interaction of this matter with radiation and magnetic fields is necessary for understanding the formation and evolution of the stars and the distribution of matter among the stars. At present, these topics are not well understood.

For these studies the UV is an important region of the spectrum because:

a. We expect significant reflection of UV by dust particles because of their predicted high scattering coefficient for short wavelengths and because hot stars emit most of their light in the UV.

b. The peak emission of the forbidden 2s to 1s two-photon transition of atomic H occurs at λ 2421.

c. Strong resonance emission is expected to occur for Mg II at λ 2795 and λ 2802.

d. Variation of Te and Ne produces marked changes in the relative intensities of the collisionally excited forbidden lines, and this effect is expected to be enhanced in the UV.

To meet the objectives above, an image tube optical system utilizing band photometry will be employed.

Employing an objective grating, a UV stellar survey can be accomplished in addition to the above objectives.

1.4.4.2.2.2 Description. In Figure 1-13, an instrument for imaging extended sources or providing objective-grating spectra is shown. The f/1.5 Schmidt system uses a MgF_2 corrector plate. A photocathode is located on the focal surface. The photoelectrons are accelerated and magnetically focused onto a phosphor-fiber optics surface. The curvature of this surface will partially correct for distortions of the electric field introduced by the curved photocathode to avoid loss of resolution. The second stage can be a standard WL 30677 image tube or a vidicon tube, each coupled to the first stage by fiber optics.

From this design, one can generate a family of astronomical instruments with various optical focal ratios. The expected resolution of the system is about 25 lp/mm or better with 6 μm fiber optics. Development efforts predict 40 lp/mm will be attainable. The

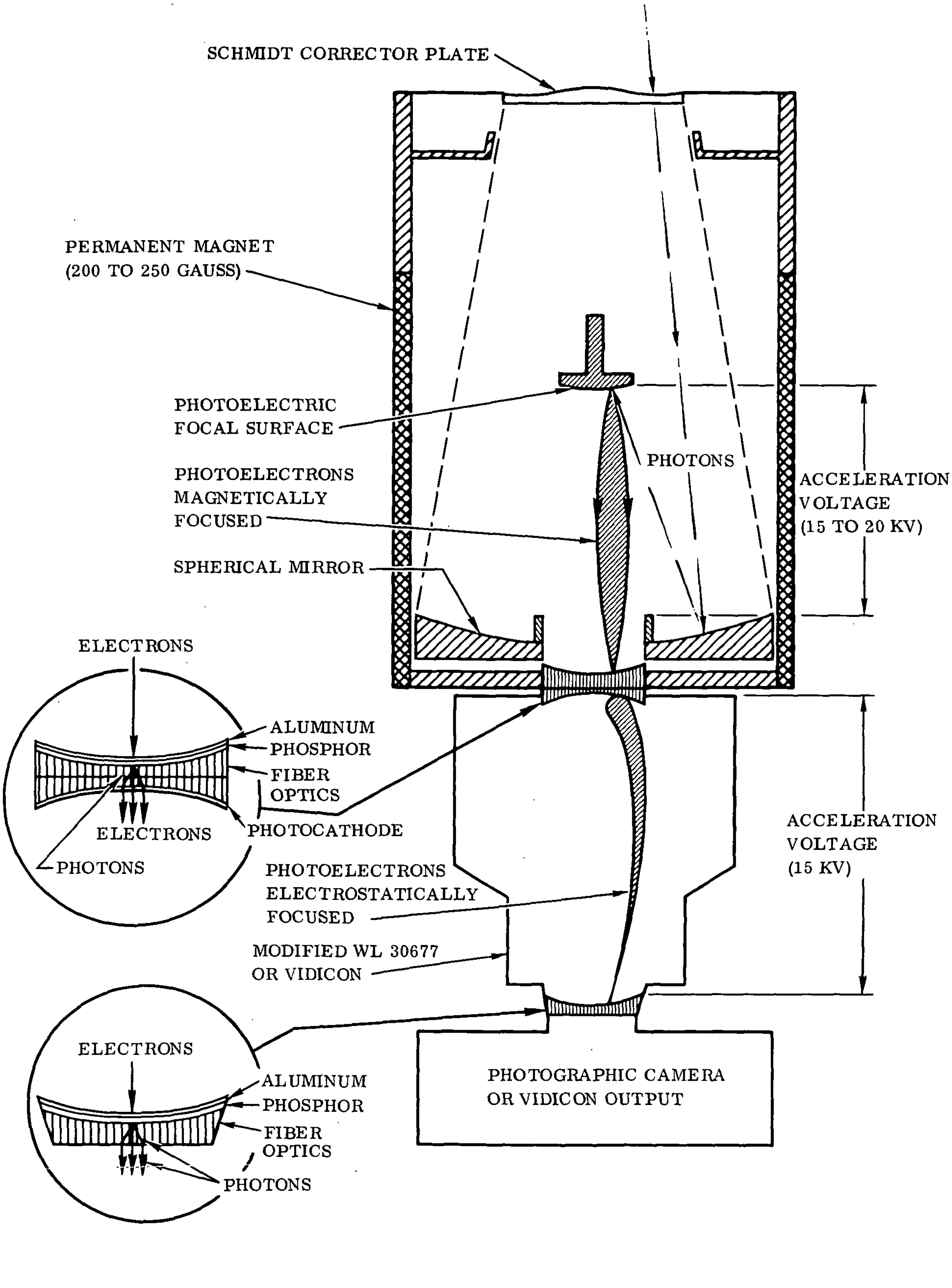


Figure 1-13. Space Image Tube Optical System

instrument as depicted in Figure 1-13 can image a 10° field on a 25 cm square exit window. With 40 lp/mm resolution at the window, this results in 35 arcsec angular resolution. A larger instrument can place the same field on a 100 cm square window, yielding 9 arcsec resolution if 40 lp/mm is attained. The gain of the camera depends on wavelength. Use of an opaque photocathode (e.g., about 40% efficiency for CsI at $\lambda = 1500$), and of a phosphor as a photon producer yields an expected photon gain of about 2500 (output photons per incident photon). Of course, the speed and/or limiting magnitude is determined largely by the focal ratio of the optics and the demagnification factor of the second stage used.

Both versions (vidicon or WL 30677) are easy to use. Normal orthochromatic II_a D film is used with WL 30677. An SEC vidicon tube with a 25.4×25.4 mm usable imaging surface and 40 line pairs/mm is currently available; a 100×100 mm usable imaging surface is planned for development. The 25.4×25.4 mm results in 10^6 picture elements and the 100×100 mm results in 1.6×10^7 picture elements.

The instrument will be capable of filter band photometry in the range 2000 Å - 3000 Å. However, the instrument described above is not suitable for very wide passbands because all available materials for the corrector plate have indexes of refraction which change very rapidly with wavelength in the UV and introduce optical aberrations. Therefore, if broad bandpass is desired, a different optical approach would be preferred. Currently, subtraction photometry may be employed to extend the shorter wavelength limit to 1000 Å. However, future development in transmission filters may allow the instrument to be used in this range without resorting to techniques of this type.

Objective grating spectroscopy is currently feasible in the range 1000 Å - 3000 Å.

Guiding will be accomplished with a coaxial star tracker, either by direct or offset guiding. Guiding accuracy to well within one arcmin is currently feasible.

1.4.4.2.2.3 Potential Role of Man. There exists many tasks which can be performed must more efficiently by man than by automated instruments. In some instances, there does not exist any other way of performing these tasks. If the equipment should malfunction, a man will often be able to repair it, especially if the instrument is designed with that capability in mind. A man can replace wornout parts. In many instances it will be less expensive to build an instrument if it does not have to incorporate redundant features which are mandatory for a completely automated space experiment. This will be particularly so when the Space Shuttle can keep at a reasonably low level the cost of transporting the man to the Space Station.

The astronaut will select the desired instrument to be used, remove it from storage and mount it in the appropriate airlock for deployment. He will check out and calibrate the instrument as well as monitor its operation. In addition, he can change gratings, thereby giving greater versatility to the instrument. He will also be able to examine the used gratings for contamination and deterioration.

1.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

The interface and support requirements which are tabulated in Tables 1-2, 1-3, 1-4, and 1-5 represent the individual requirements of each experiment category of this FPE. The requirement for the total FPE is qualified by the expectation that the experiments will not be conducted simultaneously, and hence a fraction of the power and data rates will be utilized.

The summary data presented in Table 1-12 represents, in the best judgement of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experiment program for this FPE. The rationale for selection of the summary parameters is in some instances arbitrary but it has for a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

Table 1-12. FPE Requirements Summary

Item	Requirements
Weight	2648 kg (5800 lb)
Volume	3.6 m^3 (127 ft^3)
Power	1 kW
Crew Skills	5, 6, 12
Data Rate	6,300 kilobits per second
Logistics Up (30 day average)	132 kg (280 lb)
Logistics Down (30 day average)	132 kg (280 lb)
Pointing and Stability	±8 mr (0.5°), 0.16 mr/sec (0.01°/sec)
Orbital Altitude and Inclination	> 185 km (100 n.mi.) Preferred: Polar Acceptable: 0.875 rad (>50°)
Unique Environmental Requirements	Minimum Contamination

1.6 POTENTIAL MODE OF OPERATION

The space physics research laboratory may be designed as an integral unit, or some of the experiments may be incorporated individually as supplemental payloads on various flights. A very important advantage of an integral space physics research laboratory is the ability to make the many observations and measurements simultaneously in the various spectral regions.

The FPE objectives can be met to different degrees, by each of the operational cases described below.

1.6.1 LIMITED ON-ORBIT STAY TIME (AS WITH SPACE SHUTTLE). The objectives of the atmospheric and magnetospheric science observation and measurement program include two major facets. Initially it is recommended that a complete survey be performed, involving simultaneous measurements for 24 hours per day for four days (see Table 1-2). This objective can be met within the time constraints of a shuttle-only operation which may run from 5 to 30 days. Those measurements indicated as requiring 10 days or longer can also be performed in this mode if the orbit stay time is at least that long. After evaluation of the initial survey data, subsequent observation requirements will be determined and categorized as those which can be performed in 5 to 30 days and those which require longer on-orbit periods.

The cometary physics experiments can be performed effectively in any of the possible modes of operation because of the short time required (see Table 1-3).

In the meteoroid science category, the optical meteoroid detector and the cosmic dust mass and velocity sensor experiments can be performed in a 5 to 30 day period, because they operate in the size and energy region in which many events per day are expected (see Table 1-4). The cosmic dust composition analyzer, thick material penetrations panel assembly, and the recoverable panel assembly require the extended on-orbit times because of the low rate of event occurrence.

The astronomy (small telescopes) experiments can be effectively performed in this mode, since the longest observation periods are of the order of one hour (see Table 1-5).

1.6.2 EXTENDED ON-ORBIT STAY TIME REVISITED PERIODICALLY BY SHUTTLE. It is possible for all of the experiments to be performed in this mode. The ambient environment measurements and meteoroid science experiments are effectively performed on a continuous basis, with or without the presence of the astronauts. The periodic visits will allow for maintenance functions, and hence extend the useful life of the instruments. The composition analysis experiment as presently conceived involves the use of a film readout. If extended unmanned operation is desired, longer rolls of film (appropriately shielded from radiation) could be used, or the signals could be encoded and telemetered.

Those experiments involving pointing of gimbals would have to be entirely managed by prearranged programming while the astronaut is not present. Changing of sensors, gratings, sensitivities, etc., would have to be automated, if that level of flexibility were desired to be retained during the entire orbiting period, including the unmanned portion.

1.6.3 EXTENDED ON-ORBIT STAY TIME FOR THE SPACE STATION. This mode of operation provides the greatest level of flexibility for the space physics research laboratory. The laboratory equipment and facilities may be incorporated integrally in the Space Station or they may be in an attached mode. The module may also be operable in the free flight mode as well as in the attached.

1.7 ROLE OF MAN

An important role of man in this FPE may be the exercising of technical and scientific judgement with respect to the selection of experiments to be performed as a function of current and past activities during the mission, and in the light of developing events. An example of this is the observing of transient auroral events and the pointing of appropriate instrumentation to the regions of interest. Another example of this type of function is the possible case of the astronaut-astronomer who observes unusual spectral emissions from some celestial region and then brings additional instruments and expanded scales to bear on the target.

The astronaut will participate in the deployment of various instruments, as well as in the monitoring of the operation. He can also change gratings on spectrometers, thereby giving greater versatility to the instrument. Examination of optical elements for contamination and deterioration will be possible. Another function of man will be the changing of film cartridges, as in the cosmic dust analyzer experiment

1.8 SCHEDULES

The anticipated development schedule for the SPRL is indicated in Table 1-13. The schedule indicates a parallel development of the four experiment areas, and a partially parallel development for the SPRL as an entity.

It is possible that some versions of individual experiments may be performed separately on various flights apart from the laboratory.

1.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

No special prelaunch support requirements on GSE have been identified at this time.

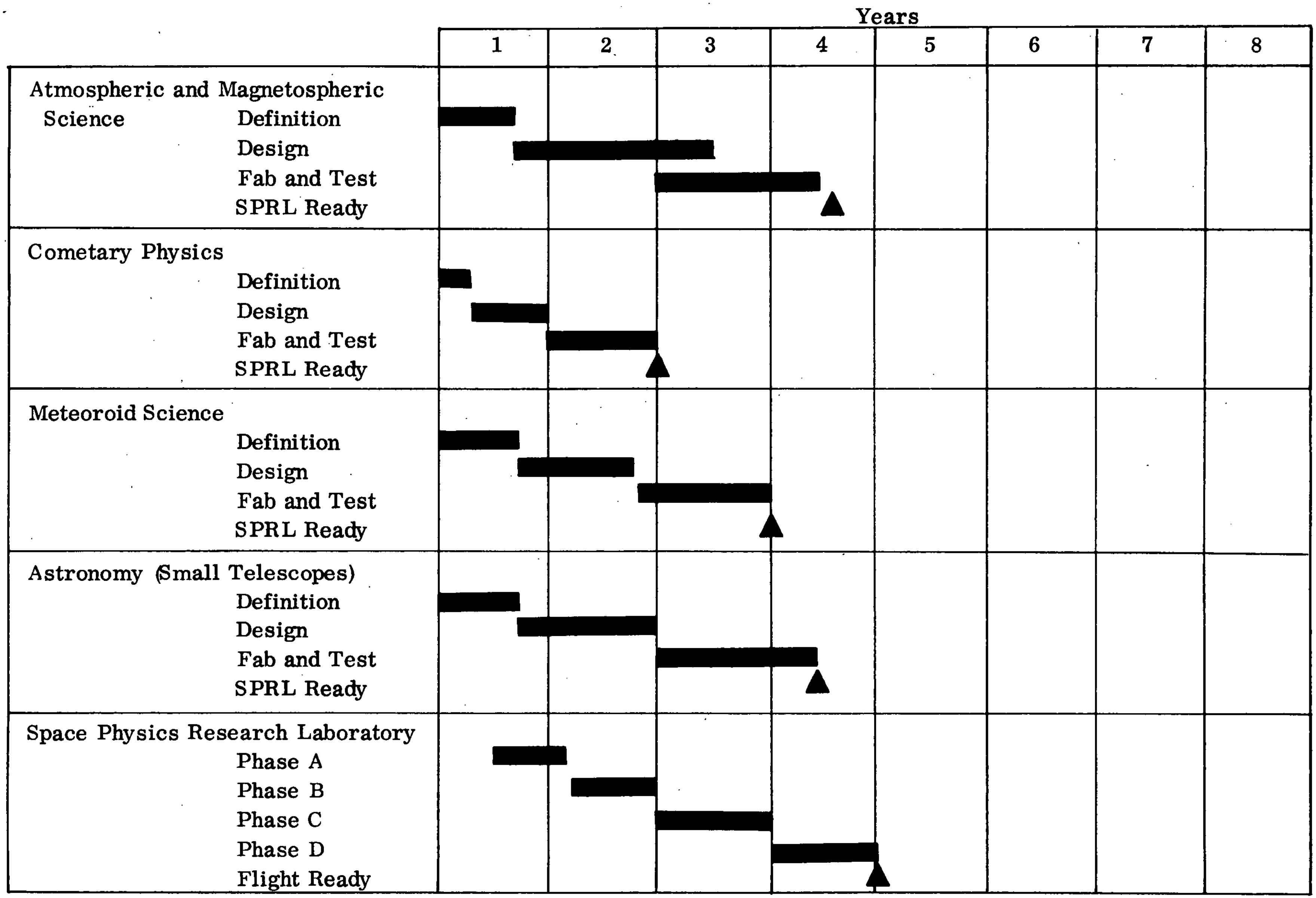
1.10 SAFETY ANALYSIS

There are no unusual safety precautions required to accommodate this FPE except for handling of the gaseous release charges for the cometary physics experiment. Care must be taken that the gases do not discharge in the spacecraft.

1.11 AVAILABLE BACKGROUND DATA

References for each experiment category have been listed in each section. The references at the end of the section describing the atmospheric and magnetospheric science experiment category includes References 1, 2, and 3 which are common for the entire FPE. Reference 4 is common for all the experiments except meteoroid science.

Table 1-13. Space Physics Research Laboratory Development Plan



VOLUME III

SECTION 2

PLASMA PHYSICS AND

ENVIRONMENTAL PERTURBATION

LABORATORY

SECTION 2

PLASMA PHYSICS AND ENVIRONMENTAL PERTURBATION LABORATORY

2.1 GOALS AND OBJECTIVES

For many years experiments on satellites have been used to make observations on the conditions that exist in our space environment. From the measurements it has been possible to determine the spatial and temporal plasma conditions which exist over a wide region of the magnetosphere. However, the processes that actually control these space plasma characteristics are still not understood. This condition is due to the fact that the processes are extremely complex, and it is difficult to resolve one process from the many that occur simultaneously. Therefore, what is now required is a series of experiments that do not just observe the plasma, but actually perturb it in a manner that may artificially reproduce the naturally occurring phenomena. A basic goal of this exercise is to define the requirements for a space plasma physics laboratory that is capable of conducting these types of investigations. The design of this kind of laboratory is inherently difficult as the equipment required to measure the various plasma parameters will depend on the region under investigation. The laboratory equipment will need to operate over a wide dynamic range or in a specific region in space. The system adopted here is to select four areas of space plasma physics that are of major interest. One particular experimental program from each area which is capable of being conducted from a specified orbit is then defined. While it is not possible at this stage to define the absolute requirements, an estimate of the type, magnitude and commonality of the equipment and the necessary level of support systems will be presented. The four main areas are:

a. The wake phenomena associated with orbital bodies.

b. Investigation of plasma resonances and their harmonics.

c. Investigation of wave/particle interactions.

d. Investigation of electron and ion beam induced perturbations.

The first proposed investigation will be to explore the wake generated in the ionospheric plasma by the motion of a spacecraft through it. This motion produces a perturbation of the ambient plasma both in front of the vehicle and to a greater degree behind it. Because of the difficulty of duplicating in the laboratory the exact conditions that occur in space, it is necessary to carry out this investigation in the space environment. The type of data generated will allow a better understanding of the response of an ionospheric type plasma to the passage of bodies through it. Several authors have theoretically investigated, in great detail, the perturbations of the ambient plasma caused by the passage of a large body[1,2,3]. At the present time, this region has been investigated experimentally for small bodies by three satellites, Explorer

VIII, Ariel I, and Explorer XXXI. However, only limited confirmation of the theoretical predictions have been achieved by the use of probes at fixed locations. An important offshoot of this investigation is that until this investigation has been accomplished it is difficult for future experimenters to ascertain where in relationship to a spacecraft one can expect to encounter an undisturbed, or ambient plasma condition in order to avoid spurious, spacecraft-produced effects.

The topside of the ionosphere above the height of maximum electron density has proven to be an excellent laboratory for the study of plasma waves. The main reasons for this are that the earth's magnetic field is strong enough to make the propagation strongly anisotropic and the plasma is essentially collisionless. Plasma resonance phenomena in space were originally observed on rocket flights and later identified with topside sounders. They appear as persistent ringing signals at the plasma frequency and multiples of the electron cyclotron and upper hybrid and other frequencies. In addition to the principal resonances, plasma echoes, proton period modulation, lower frequency resonant signals and "floating" resonances are observed. These signals[5] are thought to be a partial manifestation of the expected electrostatic waves and laboratory measurements[6] have verified the theory under different plasma conditions. Although a variety of plasma resonances have been observed on automated satellites, they have not been studied in the detail which is possible from a manned laboratory. The properties of the waves are defined by: 1) a group velocity as a function of frequency, 2) the angle between the antennas and the earth's magnetic field, and 3) the angle between the antennas and their velocity vector. This is observed as a time delay between initiation of a pulse at one antenna and observation of the pulse at another antenna separated from the first antenna by a fairly large distance. What is now required is a determination of these characteristics for the observed space resonances and the sensitivity of the characteristics to input power and antenna orientation.

The prime purpose of the VLF experimental group is to study the possible modification of the environment of the magnetosphere by injecting whistler mode waves from the space station and the ground. Observations of such wave-induced phenomena should aid in understanding the physics of wave-particle interaction processes and provide a basis for systematic artificial modification of the waves and the interacting particles. An early technical objective of the laboratory will be to obtain information and experience in the operation of high powered VLF transmitters and their associated large antennas. Earlier space flights have observed naturally-produced whistler mode impulses from lightning and emissions from the magnetosphere and ionosphere. Artificial transmissions from space vehicles have been of very low power and mainly from sounding rockets. However, the large transmitters proposed for the space plasma physics facility will enable not only wave propagation, wave-particle interactions and wave stimulation studies to be carried out but would also allow the concept of magnetospheric plasma control to be studied. Furthermore, the possibility of establishing a new communications system is an interesting practical objective. This system could perhaps try to make use of the theoretically-proposed principle of natural magnetospheric VLF amplification.[7]

The objective of the electron and ion beam propagation experiment is to use the particle beams as probes to study plasma and atmospheric processes and the magnetospheric configuration. Particle beams have been in general use in the formation and study of laboratory plasmas for some time, but only recently has their use been applied to space applications. In addition, they can be used to generate EM waves and to modify the particle population in a tube of force of the earth's magnetic field. Two electron beam experiments have demonstrated the capability of a 5 kilowatt beam to produce an artificial auroral ray[9] and also for a 40 keV low intensity beam[10] to be reflected back from its conjugate position in the other hemisphere and be detected by the injecting vehicle. These experiments have demonstrated the feasibility of producing electron beams in space, and detecting their effects. Also, an elaborate electron beam system[8] has reached the design stage, but the amount of experimental data on particle beam propagation in space is rather limited. No experimental ion or plasma beam system has been experimentally tested in space although related ion propulsion systems are being tested.

As well as the future growth that will occur in these four categories, a further such area is the class of experiments which would seek to do laboratory-type experiments within the ambient ionospheric plasma unhampered by wall and end effects which can produce spurious results. Because one can make observations of plasma phenomena over extremely large distances if one is in the ionosphere, it will be possible to extend the wave-wave, and wave-particle interaction experiments, which are presently being done in laboratories, to very much larger wave lengths if the experiments are carried out in the ionosphere. These effects can be minimized in the ionosphere. These experiments would be what could be called basic plasma physics as opposed to the preceding class of experiment which would be termed ionospheric plasma physics. The 1968 Woods Hole Conference report points out a need to do these kinds of experiments.

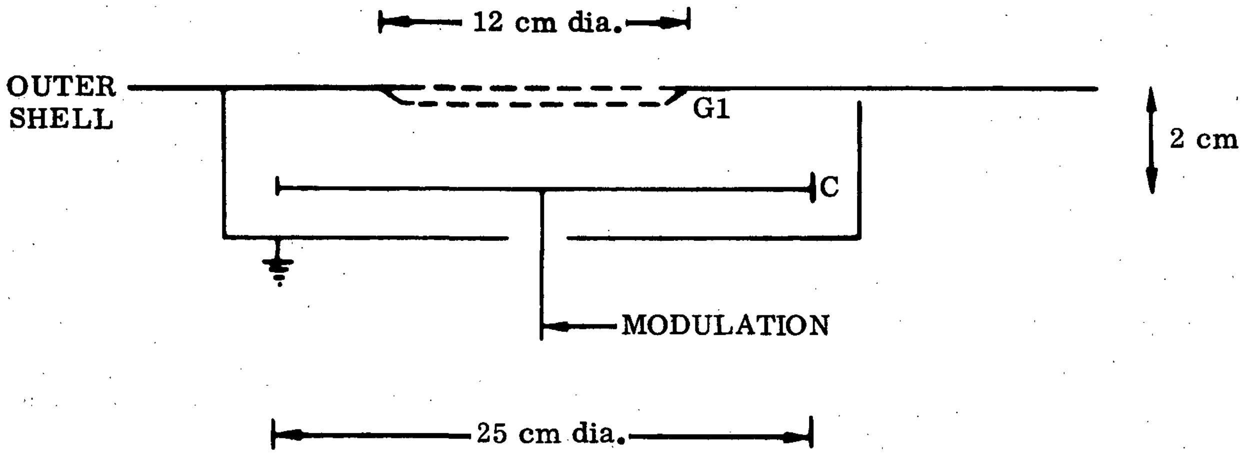
Finally, it is important to consider another associated group of experiments. These involve a determination of the energy input from both earth and solar sources which produces the ionization observed in the ionosphere. There has been a tendency to disperse this set of experiments into other areas such as solar physics, x-ray spectra, low energy particle fluxes, etc., but it is important to remember that these energy and ionization sources have a paramount effect upon the character of the ionosphere.

2.2 PHYSICAL DESCRIPTION

This section contains sketches (Figures 2-1 through 2-15) of typical instruments and their main characteristics which are required to conduct the required experimental program (Tables 2-1 through 2-6). The selection of instruments has been made to represent a typical payload, but is not meant to specify the ideal instrument.

2.3 EXPERIMENT REQUIREMENTS SUMMARY

Table 2-7 contains a summary of support requirements of representative classes of plasma physics experiments.



DATA

Grid G1 -5 to +4V

Collector +25V

MATERIAL

Grids Gold-plated 100-mesh tungsten wire, 0.0254 mm (0.001 in.) D suspended on 5 cm (2 in.) squares of 0.254 mm (10-mil) tungsten wire

Transparency ~67%

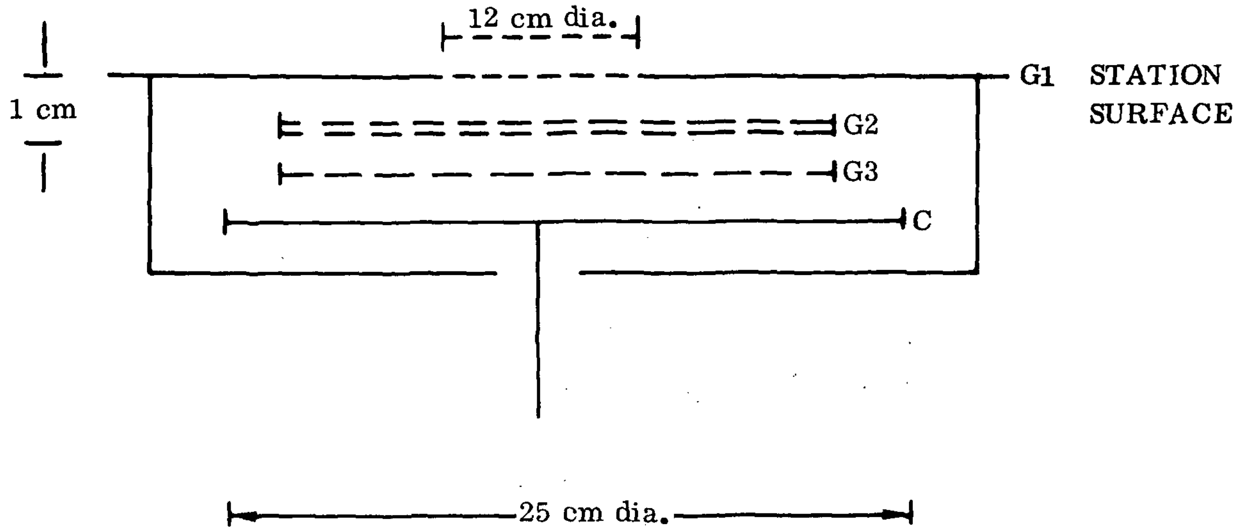
Weight: Space Station, 6 kg (13 lb)
Subsatellite, 2.5 kg (5.5 lb)

Volume: Space Station, 1.5×15^{-3} m^3 (5.3×10^2 ft^3)
Subsatellite, $5 \times 10^{-4} m^3$ (1.7×10^{-2} ft^3)

Power: 12 watts

Data: 10^4 bps

Figure 2-1. Electron Density and Temperature Measurement Device



DATA

Grid 1 Various Potentials ⟶ 20 V Negative

Grid 2 Retarding Analyzer, 0 to 7 V Positive

Grid 3 Inhibit Secondary Electrons, -15 V Negative

Collector Collection of Ions, -2V Negative

MATERIAL

Grids Gold-plated 100-mesh tungsten wire, 0.0254 mm (0.001 in.) D, supported, if necessary, on 5 cm (2 in.) squares of 0.254 mm (10-mil) D wire

Collector Gold Plated

Transparency 50%

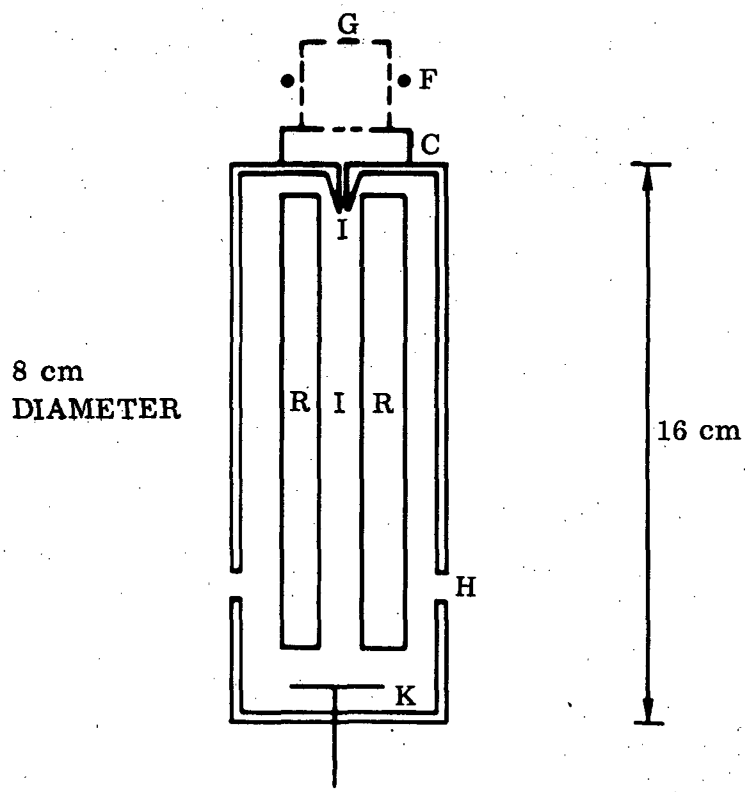
Weight: Space Station, 6 kg (13.1 lb)
Subsatellite, 2.5 kg (5.5 lb)

Volume: Space Station - 1.5×10^{-3} m^3 (5.3×10^{-2} ft^3)
Subsatellite - 5×10^{-4} m^3 (1.7×10^{-7} ft^3)

Power: 13 watts

Data: 10^4 bps

Figure 2-2. Planar Thermal Ion Trap



F = Filament

G = Acceleration Grid

C = Ground Plane

I = Ion Inlet Port

R = Analyzer Rods

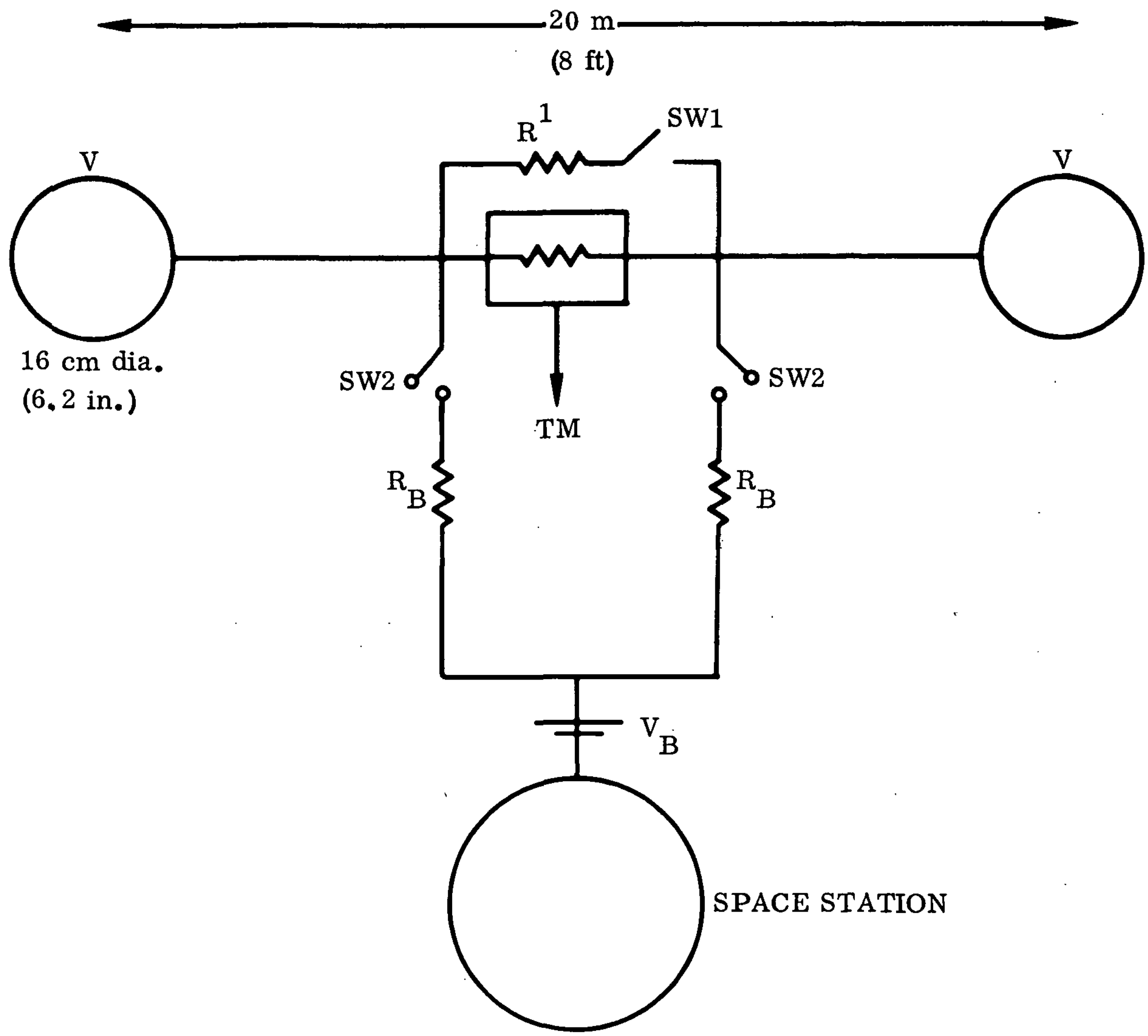
K = Ion Collector

H = Gas Pumping Ports

System will operate without filament section when used in ion mode.

Range:	1 - 46 amu
Weight:	8 kg (17.7 lb)
Power:	18 watts
Volume:	8×10^{-4} m^3 (2.83×10^{-2} ft^3)
Data:	10^4 bps

Figure 2-3. Quadruple Mass Spectrometer



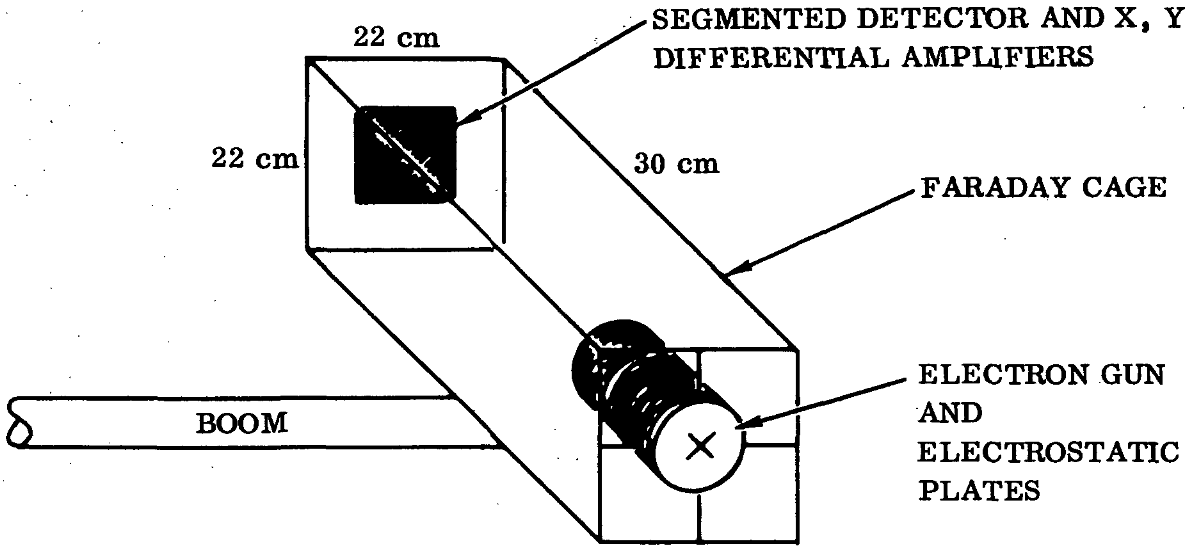
1. AC fields over range DC to 1 MHz of amplitude 0.1 - 1000 μV/meter $(Hz)^{1/2}$.
2. DC fields 0.1 - 400 mV/meter to 1% accuracy.

Weight: 6.4 kg (14.1 lb)

Power: 20 watts

Data: 10 MHz analogue

Figure 2-4. Measurement of AC Electric Fields



VOLUME: 1.4×10^{-2} m^3 (5×10^{-1} ft^3)

ELECTRONICS IN SPACECRAFT: 2,000 cc 2×10^{-3} m^3 (7.1×10^{-2} ft^3)

POWER: 50 watts

DATA: 10^3 bps

BEAM DIAMETER: 0.1 cm (1/16 in.)

METHOD: The E field deflection of the beam is modulated by removal of the Faraday cage, whereas the magnetic field deflection is constant.

Figure 2-5. Measurement of DC Electric Fields

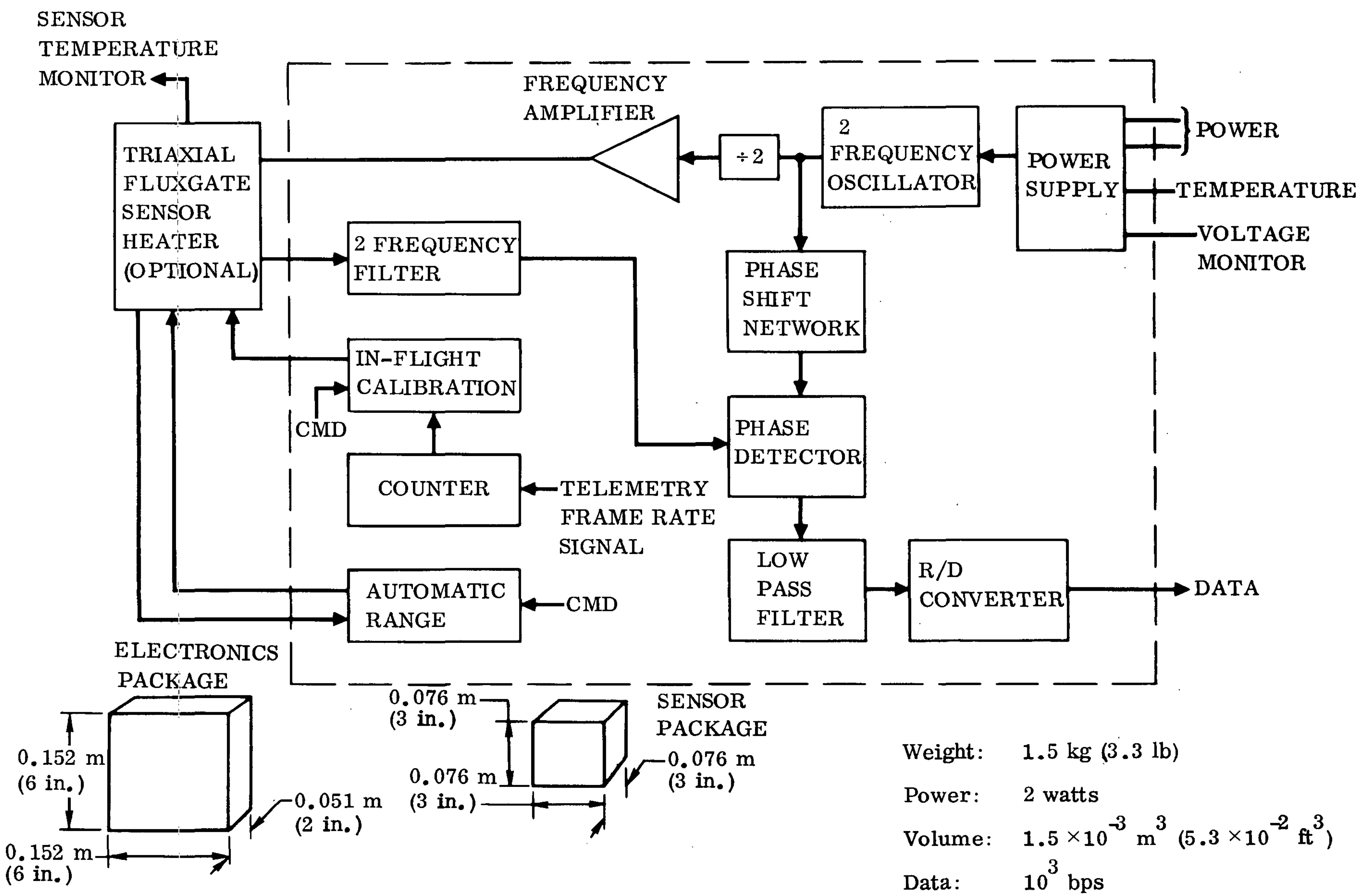
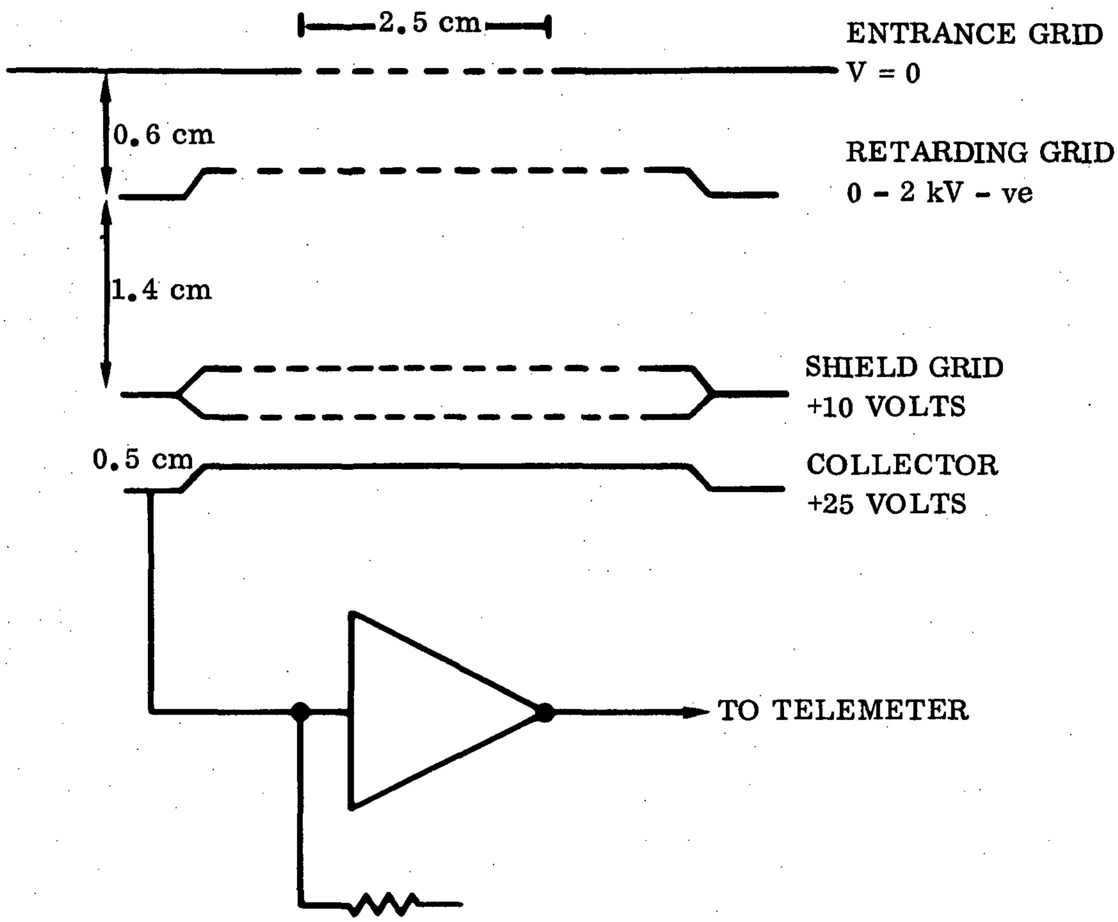


Figure 2-6. Fluxgate Magnetometer



MATERIAL

Grids Gold-plated 100-mesh tungsten wire, 0.0254 mm (0.001 in.) D

Collector Gold Plated

Transparency ~70%

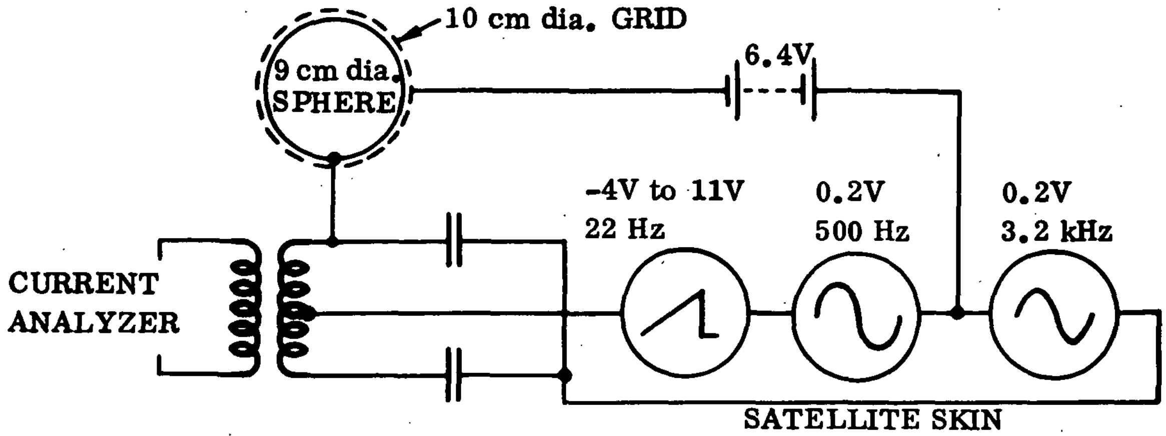
Weight: 1.5 kg (3.3 lb)

Power: 5 watts

Volume: 5×10^{-4} m^3 (1.5×10^{-2} ft^3)

Data: 10^4 bps

Figure 2-7. Measurement of Suprathermal Electrons

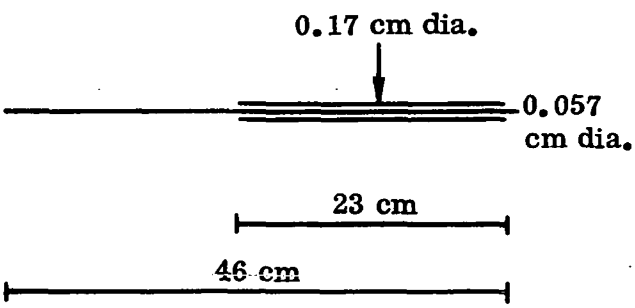


The plated sphere is surrounded by a gold plate spherical grid to remove electrons. Tunable LC bridges are used to balance out internal impedances in order to achieve maximum sensitivity. The current analyzers employ a variable gain amplifier with frequency selection in the range 2.7 to 3.7 kHz, the output being detected and applied to two low-pass filters. The first low-pass filter has a bandwidth of 40 Hz, so that its output is a function only of the 3.2 kHz carrier level and this controls the amplifier gain, through a delayed AGC circuit; the AGC voltage is extended as a measure of carrier current. The second low-pass filter passes the 500 Hz modulating frequency, and since the carrier level at its input is constant, the output is directly proportional to the modulation depth of the probe current.

Weight: 2 kg (4.4 lb)
Volume: 2×10^{-3} m^3 (7.5×10^{-2} ft^3)

Power: 10 watts
Data: 10^4 bps

Figure 2-8. Spherical Ion Probe

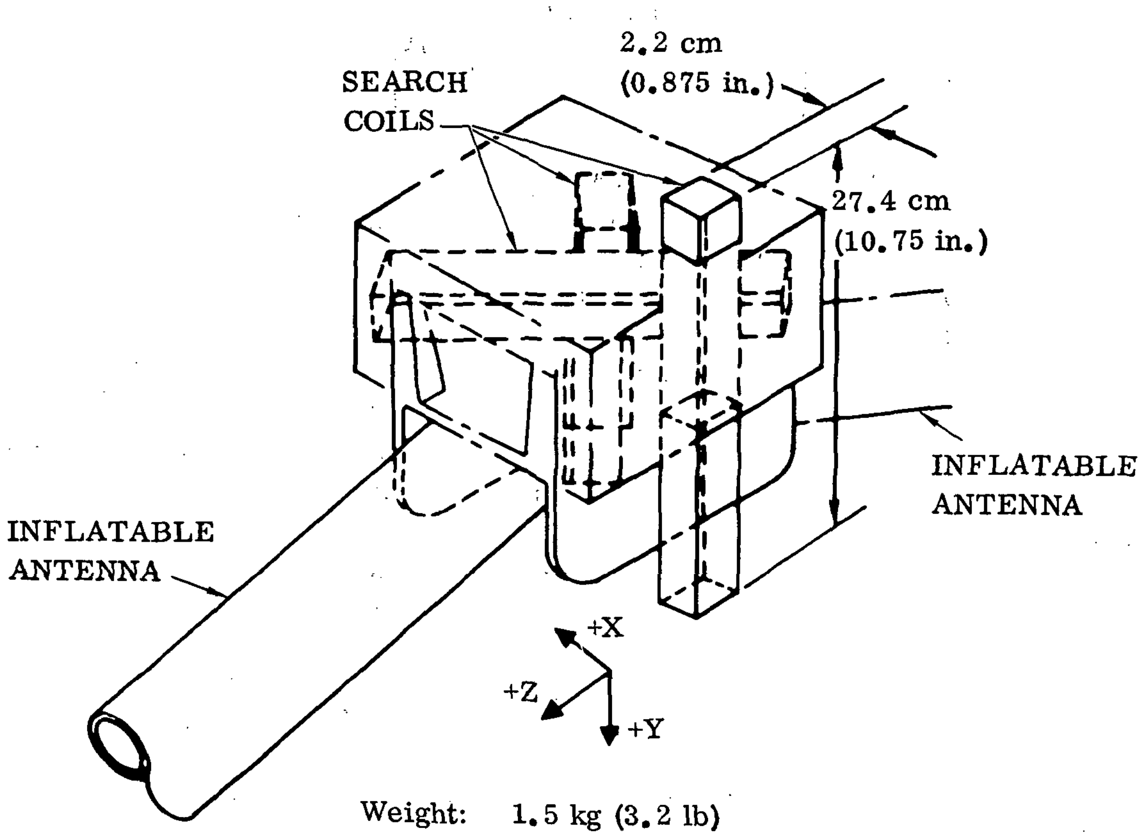


MATERIAL
Stainless Steel - Rhodium Plated

ELECTRONIC HOUSING
5 x 12 x 15 cm

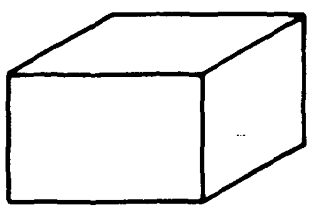
Weight: 1.5 kg (3.3 lb)
Volume: 9×10^{-4} m^3 (3.16×10^{-2} ft^3)
Power: 2 watts
Data: 10^4 bps

Figure 2-9. Cylindrical Electrostatic Probe



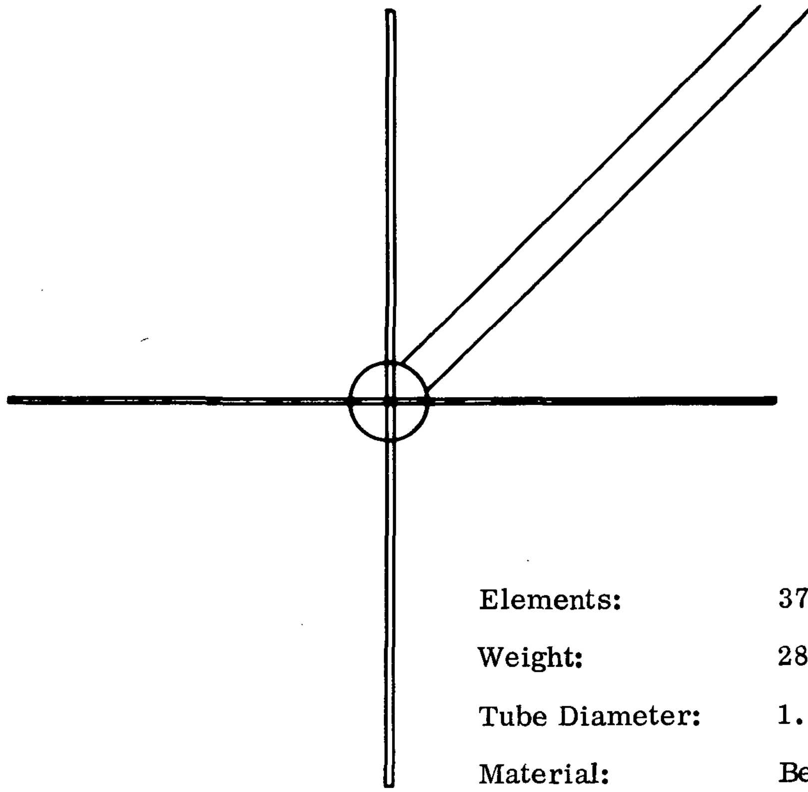
Weight:	1.5 kg (3.2 lb)
Volume:	1.7×10^{-3} m^3 (0.06 ft^3)
Power:	2 watts
Data:	10^3 bps

Figure 2-10. Search Coil



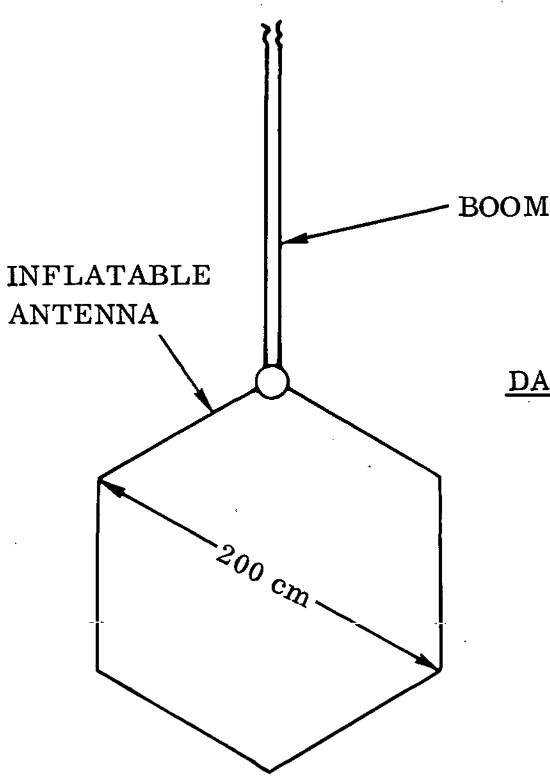
Frequency Range:	0.1 - 200 kHz
Weight:	69 kg (150 lb) Additional battery weight - 200 kg (4400 lb)
Volume:	4.8×10^{-3} m^3 (1.75 ft^3)
Power:	Estimate - 1 watt to 10 k watts peak power. Average - 10 to 50 watts

Figure 2-11. Transmitter VLF



Elements:	37.5 m (123 ft) tip to tip
Weight:	28 kg (61 lb) boom not included
Tube Diameter:	1.25 m^3 (0.5 $in.^3$)
Material:	Be/Cu STEM

Figure 2-12. VLF Antenna



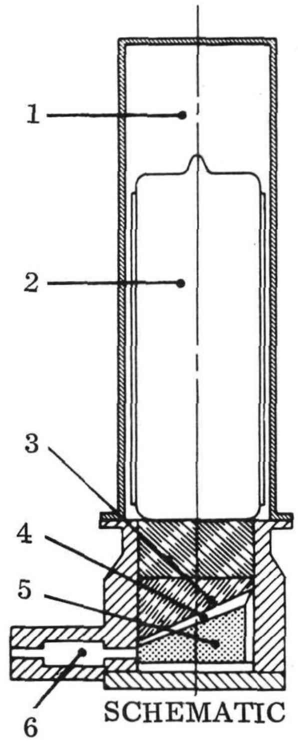
DATA

Antenna is inflated when in orbit and mounted:

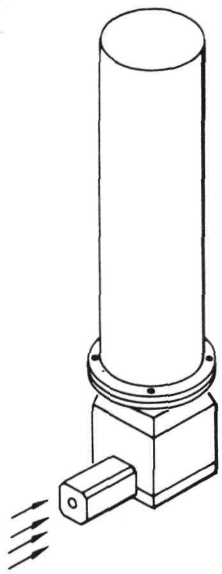
1. From boom on space station
2. On subsatellite

Dimensions:	2 m (6.56 ft) dia., 10 to 100 turns
Power:	N/A
Weight:	1.4 kg (3 lb)

Figure 2-13. Magnetic Antenna for VLF

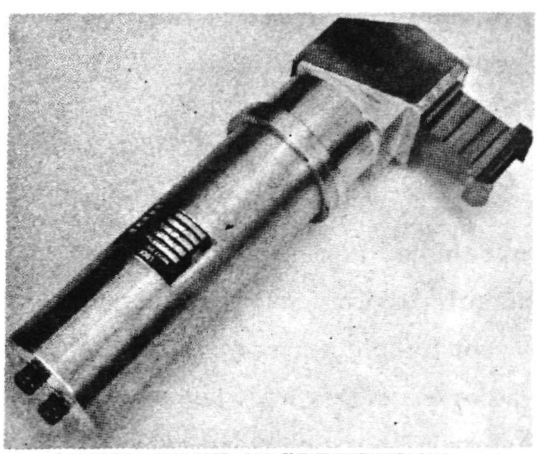


SCHEMATIC



1. Electronics
2. Photomultiplier
3. Light Pipes
4. Plastic Scintillator
5. Magnet
6. Collimator and Shield

Volume:	4×10^{-3} m^3 (1/6 ft^3)
Power:	3 watts
Weight:	44 kg (2 lb)
Data:	10^4 bps


ASSEMBLED INSTRUMENT

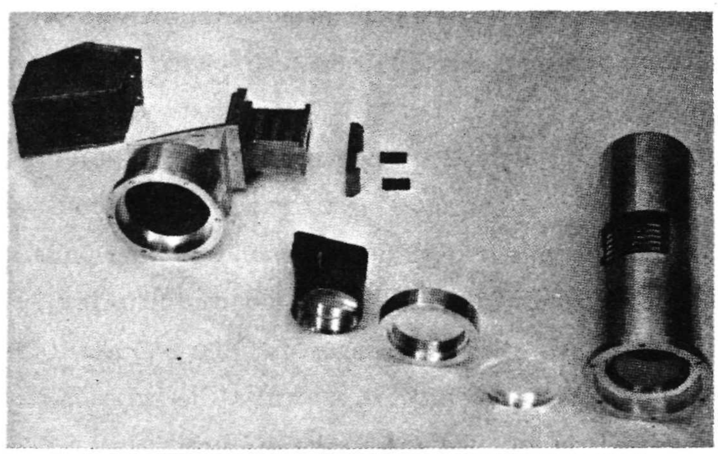
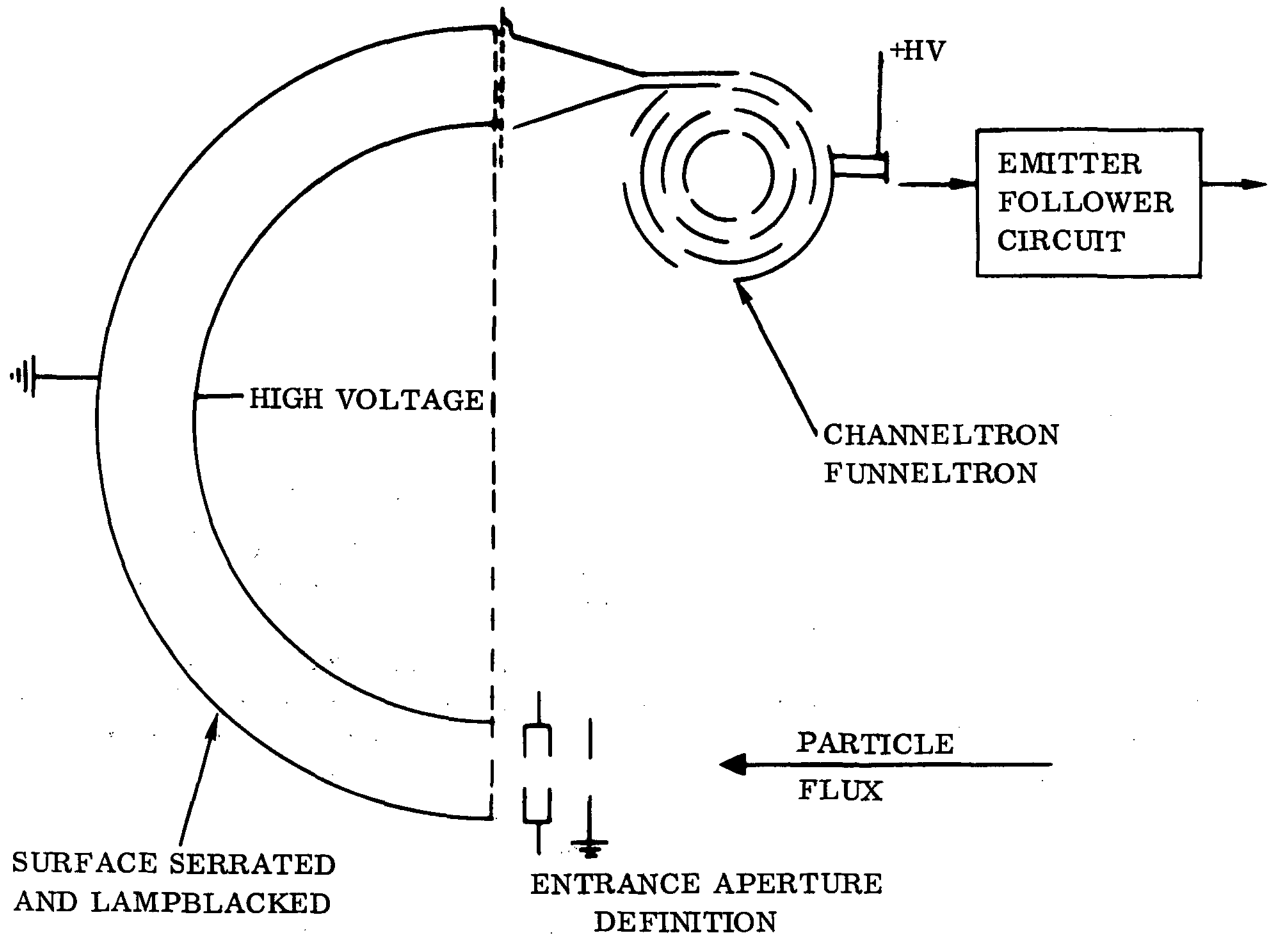

PARTIALLY ASSEMBLED INSTRUMENT

Figure 2-14. Electron Scintillation Spectrometer



DIMENSIONS:	Two hemispheres of 10 cm (3.9 in.) outside radius 11 cm (4.3 in.) inside radius
POWER:	0.5 watts
WEIGHT:	1 kg (~ 2 lb)
ANALYSIS:	Swept Voltage
DATA:	10^4 bps
OPERATION:	A. Fixed Voltage ______ Fixed Energy Range B. Limited Voltage Sweep ______ Limited Energy Range C. Full Voltage Sweep ______ Full Energy Range

Figure 2-15. Hemispherical Analyzer

Table 2-1. Balloons

Inflated Form			
Sphere	30-m (100 ft) dia.		
Cylinder	30-m (100 ft) dia. 40-m (130 ft) long		
Material			
Conducting Surface			
Low Rate of Gas Loss			
Weight			
Sphere:	23 kg (50 lb)	Cylinder:	23 kg (50 lb)
Container:	4.5 kg (10 lb)	Container:	4.5 kg (10 lb)

Table 2-2. Investigation of Plasma Resonances and Their Harmonics

Equipment	Size Meters	Volume Meters^3	Weight kg (lb)
RF Transmitter	$0.15 \times 0.15 \times 0.05$	1.3×10^{-3}	3(6.6)
RF Antennas 1) Resonance 2) Transmission	2 at 73.2 2 at 18.8 2 at 20	0.03 0.008 0.01	15(33) 15(33) 6.5(14)
Associated Electronics	--	0.01	8(17.6)
Boom Boom Cables	20 20	0.04 0.01	4.5(10.4) 3.3(7.3)

Table 2-3. VLF Electronic Receivers

Type:	• Broadband 1 - 100 khz spectral receiver • Six narrow band 1 Hz - 3 khz bandwidth receiver which can be commanded to have any center frequency 2-99 khz • Two 100 Hz band pass receivers. These can operate from any of the 3 khz band pass receivers
The above receivers can accept on command	a. Any preamplifier output b. Sum or difference of any preamplifiers c. Sum of any preamplifier outputs either shifted by ±90°.
Volume:	$8.8 \times 10^{-4}\ m^3$ (0.3 ft^3)
Weight:	4.6 kg (10 lb)
Power:	20 watts

Table 2-4. High Energy Electron Measurement Device

Range:	20 - 500 keV
Type:	Electron scintillation spectrometer as used in Lockheed auroral input-output experiment. The input electron flux is swept by the magnet into the plastic scintillator while the heavy ions are unaffected and do not reach the scintillator. The scintillator-photomultiplier system feeds a pulse height analyzer. In-flight calibration by placing a weak Po^{210} alpha source near the scintillator.
Response:	Millisecond
Power:	1 watt
Size:	$4.3 \times 10^{-3}\ m^3$ (~12 × 3 in. dia.)
Weight:	1 kg (~2 lb)

Table 2-5. Low Energy Range Analyzer

1.	For use up to a voltage of about 2 kV, a retarding potential analyzer with appropriate load for required time response could be used if flux is large enough. See wake experiment.
2.	Region of 0.5 to 20 keV. Hemispherical electrostatic analyzer with channeltron particle analyzer operated in current mode. The inner sphere is swept either over the whole energy range or over an interesting portion of the range.

Table 2-6. Electron Accelerator

Accelerator is composed of essentially three sections:

1. ELECTRON GUNS - The electron gun system is at present not defined, but possibilities are:

   A. Hot filament

      a. Tungsten
      b. Oxide coated

   B. Plasma

   Their main disadvantages here are: type Aa is brittle after initial use; type Ab is easily poisoned and type B is complex. The circuitry will be required to minimize high voltage discharge but also able to withstand and terminate any discharge which does occur.

2. POWER SUPPLY - Two possibilities are suggested:

Supply	Power		Total Weight kg (lb)	Support	Volume m^3 (ft^3)	Disadvantages
	Used	Obtained				
Batteries and Static Inverter	Solar Array 75 watts	14 Kw/sec operation	230 kg (500 lb) Ni-Cd	Charging 6 hrs	0.283 (10)	Limited power
Hydrazine Turbo Alternator	Hydrazine	6.5 Kw/ unit continuous	16 kg (35 lb) plus fuel	Fuel 1.4 kg/op (3 lb/op.)	0.425 (15)	Noise, contamination of environment, vibration

3. CONTROL CIRCUITRY - Possible plan is to use electromechanical programmers due to reliability and power levels in use.

Table 2-7. Plasma Physics Experiment Requirements Summary

Experiment	Stabilization	Pointing	Thermal Control °K (°C)	Minimum Crew Support	A Measurement Period: Pulse	A Measurement Period: Observation	Highly Desirable Satellite Support Level But Not Mandatory	Equipment Weight kg (lb): Space Vehicle	Equipment Weight kg (lb): Each Sat.	Volume meters³ (ft³): Space Vehicle	Volume meters³ (ft³): Sub-Sat.	Power	Power (subsatellites)	Data Rates Minimum
WAKE 2.4.1	1°/min	1/2°	263° to 313° (-10° to +40°)	One Physicist One Engineer or Electromechanical Technician	N.A.	~1 Week	3 Subsatellites	Data Storage not Included 200 (420)	17 (38)	0.2 (7)	0.003 (0.1)	250 watts over 1 week/month for space station	50/subsatellite watts over 1 week/month for 3 subsatellites	10^5 bps Continuous
HARMONIC RESONANCE 2.4.2	0.25°/min	<1°	268° to 313° (-5° to +40°)	One Physicist One Engineer or Electromechanical Technician	Sec	Experiment 15 min period per orbit	1 Subsatellite	50 (110)	9 (20)	0.15 (5.2)	0.05 (1.5)	100 watts/orbit average power		10^5 bps
VLF 2.4.3	1°/min	1°	273° to 313° (0° to 40°)	One Physicist One Engineer or Electromechanical Technician	Several 1 sec pulses.	15 min per orbit per day	1 Subsatellite 1 Satellite	110 (242)	10 (22)	0.2 (7)	0.05 (1.5)	25 watts continuous power		12 Channels 10^4 bps 500 kHz
PARTICLE BEAMS 2.4.4	1°/min	1°	273° to 313° (0° to 40°)	One Physicist One Engineer or Electromechanical Technician	Several 1 sec pulses	15 min per orbit per day	1 Conjugate Satellite	200 (420)	9 (20)	0.9 (31)	0.11 (3.5)	100 watts continuous power		9 Channels 10^5 bps 1 MHz
TOTAL								550	N.A.	1.4	N.A.	350 watts average		3 M bps

2.4 EXPERIMENTAL PROGRAM

2.4.1 INVESTIGATION OF THE PLASMA WAKE AROUND ORBITAL BODIES

2.4.1.1 Scientific and Technical Objectives. The interaction of a space vehicle with its environment causes a perturbation of the local ambient plasma surrounding the vehicle. This region of disturbance extends in all direction from the vehicle, especially in the backward direction, and is called the vehicle's wake. The primary objective of this investigation is to determine the spatial extent and characteristics of the wake region surrounding the station. These measurements, together with studies that will be conducted on other large inflatable bodies of different sizes and shapes, will provide the necessary experimental data for comparison with the existing theory, and will enable a more complete theory to be developed. The effect of applying different potentials to the space vehicle will also be studied so that more practical estimates of wake extent can be made for future spacecraft. Besides the important contributions these objectives will provide wake physics in general, they will also enable future experimenters to ascertain where, in relation to the space vehicle, one can expect to find undisturbed plasma conditions.

2.4.1.2 Experiment Description. The spatial extent of the wake region depends upon the magnitude of the local magnetic field, the space vehicle characteristics, and the ambient plasma parameters. The important space vehicle characteristics are size, shape, potential, and the direction of its velocity vector with respect to the local magnetic field. These characteristics can be examined by the growth of the laboratory from the lone module configuration to the module-space shuttle combination to the final space laboratory complex, and by a selection of passive inflatable objects.

The plasma parameters that are affected by the presence of a space vehicle are: 1) the electron temperature, T_e; 2) the electron density, n_e; 3) the ion species; 4) the temperature of each of the ion species, T_i; 5) the density of the ion species, n_i; 6) the type of waves produced in the plasma; 7) the neutral gas parameters; and 8) fluctuating and steady state electric fields. These parameters need to be measured as a function of direction, distance from the space vehicle, the time, and the ambient plasma. Theoretical predictions[1,2] indicate that the extent of the wake region of the initial plasma physics module will be approximately 30 meters in the forward and lateral directions and 300 meters in the backward direction. For ease of investigation, this region will be divided into three sections: 1) the Debye sheath region near the spacecraft, 2) the region out to about five facility radii, and 3) the remainder -- the far wake.

In the near wake region the Debye sheath measurements will be carried out from the actual spacecraft. The instruments, which are tabulated in Table 2-8, will consist of flush-mounted, retarding potential analyzers to measure n_e, n_i, T_e, T_i, and ϕ, the surface potential, while detailed local gas composition will be obtained from a mass spectrometer. These diagnostics will be positioned around the space station to obtain

Table 2-8. Representative Selection of Diagnostics on Space Station Surface

Program	Electron Density	Ion Density	Electron Temperature	Ion Temperature	Gas Analysis
Method	Electron Trap	Thermal Ion Trap	Electron Trap	Thermal Ion	Closed quadrupole mass spectrometer
Range	5 - 10^6 e/cm^3	5 - 10^6 I/cm^3	500 - 20,000°K	500 - 10,000°K	Mass 1-46 amu, Dynamic range 10^8
Accuracy	± 10%	±2%	±200°K	±150°K	10% valley at mass 25
Analysis	Retarding Potential	Retarding Potential	Retarding Potential	Retarding Potential	RF
Other Parameters Necessary	Sun Angle	1. Grid Transparency 2. Station Potential 3. Angle V_s (↳ Sensor) 4. V_s	Sun Angle	As for ion density	Calibration
Other Parameters Obtained	Surface Potential ∅	∅	Surface Potential ∅	∅	Pressure
Field of View	± 3°				
Pointing Accuracy	± 0.5°				
Figure Number	2-1	2-2	2-1	2-2	2-3
Reference	6	7,8	6	7,8	9

the maximum possible sheath coverage. The space station outer skin should form the best conducting surface possible, and should have the minimum of protuberances which may complicate measurement. Any structure on the space station surface likely to cause large potential changes should be electrically isolated from the main body, but will preferably be removed if likely to cause appreciable local plasma variations.

The region out to about five space station radii will be examined with boom-mounted sensors. The booms will also be constructed and situated so as to investigate the maximum volume possible of the near wake, but will themselves complicate the measurements due to their own wake. The diagnostics in Table 2-9 are for boom mounting, and will measure n_e, n_i, T_e, T_i, and ϕ, besides including sensors for electric and magnetic field determination.

The far wake volume will ideally be covered by several subsatellites concurrently, one of which will measure undisturbed ambient plasma conditions. If the satellites are free-flying, they will be moved over the required volume by their propulsion system. Ideally, this system will not cause changes in the local plasma parameters, and therefore would be perhaps a tethered or reaction system. If the normal gas propulsion system is used, it will be necessary to propel the subsatellite to a point, stop it, turn off all propellant sources which could contaminate a probe, and wait until all propellant contaminants have dissipated. The control of these maneuvers will be under the direction of the on-board engineer, while the scientist monitors the experimental data.

The subsatellite will be as small as possible, and therefore will contain the minimum number of diagnostics (Table 2-10) necessary to determine the main plasma parameters and the wake boundary. Also, diagnostics will be included on the satellite to determine if non-Maxwellian electron distributions and plasma waves are present. The wake boundary will vary with time due to plasma and magnetic field changes, and therefore many measurements will be necessary over long periods of time.

In order to study the effect that different body sizes and geometries have on wake production, two large inflatable objects, similar to "ECHO"[3] will be launched at different times from the space station. These bodies will be a sphere and a cylinder, and will possibly be tens of meters in radius and have outer skins of either conducting or insulating material. Except for their inherent gas leakage, the passive nature of these bodies will provide more ideal conditions than the space station for wake measurements. The wake caused by these bodies will be monitored with the space station and subsatellite. Studies will also be carried out on the interaction between the wakes of the body and the space station.

Measurements of the ambient plasma parameters can be obtained from topside sounder[4] and VLF[5] equipment, which will also be in use in the space laboratory. This equipment will provide measurements of electron density, temperature, and ion composition.

Table 2-9. Representative Selection of Diagnostics on Space Station Booms

Program	Electron Density (n_e)	Ion Density (n_i)	Electron Temper-ature	Ion Temper-ature	Electric Field A.C.	Electric Field D.C.	Magnetic Field B	Ion Density
Method	Cylindrical electrostatic probe	Spherical ion probe	Cylindrical electrostatic probe	Spherical ion probe	Spherical conductors	Electron beam	3 axis fluxgate	Planar probe
Range	50 p/cm^3 10^6 p/cm^3	50 p/cm^3-10^6 p/cm^3 1 - 16 amu	400°K - 15,000°K > 10^4 e/cm^3	500°K - 20,000°K	Plasma frequency D.C.	0.1 mV/m to 1 V/m	0.5 - 0.1 gauss	5-10^6 = 1 cm^3
Accuracy	10%	±2%	10%	±150°K	0.1 to 1000 μV/m	0.5 mV/m at 0.1 mV/m	100 γ	10%
Analysis	Maxwellian retarding potential	Retarding potential Druyvesteyn modu-lation	Same as n_e	Same as n_i	Potential difference	Beam de-flection	Analysis of har-monic produced	Retarding potential
Other Pa-rameters Necessary	V x B work function $kT_e \gg \phi$	1. Velocity-space vehicle 2. Grid transparency for each mass	Same as n_e	Same as n_i		B field V_s		Same as n_i
Other Pa-rameters Obtained	∅		∅		D.C. fields	None		Provides directional capability
Field of View	4π	4π	4π	4π	4π	4π	N.A.	2π
Pointing Accuracy	1°	1°	1°	1°	1°	1°	0.5°	1°
Figure No.	2-9	2-8	2-9	2-8	2-4	2-4	2-6	2-2
Reference	9	7	9	7	10,11	10,11,12	13	7,8

Table 2-10. Representative Selection of Diagnostics for Wake Subsatellites

Program	Electron Temperature and Density	Ion Temperature and Density	Ion Mass Analysis	Alfven Waves	Suprathermal Electrons
Method	As for space station surface. Scaled to suit satellite	As for space station surface. Scaled to suit satellite	Open quadrupole mass spectrometer	Search coil	Retarding potential analyzer
Range			1-46 amu	0.01 - 1000 Hz	10^4 e/cm^2 sec to 10^{10} e/cm^2/sec 0.25 - 200 eV
Accuracy			10% valley at mass 25	10 μV/meter	10%
Analysis	Retarding potential	Retarding potential	RF field on static electric field	dB/dt	Retarding po-potential
Field of View	±3°	±3°	2π	N.A.	3°
Pointing Accuracy	±0.5°	±0.5°	0.5°	0.5°	0.5°
Figure No.	2-1	2-2	2-3	2-10	2-7
Reference	6	7,8	9	OGO 4	9

2.4.1.3 Observation/Measurement Program. The ideal study of the region that is perturbed by the passage of a space vehicle would be one that was performed continuously. In this manner the many variations in the wake characteristics due to such processes as solar disturbances, day-night variations, changes in the vehicle surface coefficients and seasonal variations can be studied to determine their relative importance. This mode of operation is impractical due to the need to conduct other experiments from the space laboratory and the difficulties in handling and understanding the vast amount of data that would be generated. A practical solution to this difficulty would be to study specific regions in detail for an extended period of time. A reasonable estimate would be six months of data collection over a total period of about two years.

A selection of instruments to study the plasma parameters which contribute to the formation of the wake region is displayed on Tables 2-8 through 2-10. The selection of instruments has been made to represent a typical payload, but is not meant to specify the ideal instrument for the study. This selection would require a much deeper appraisal than is possible at this stage. As the three regions of the wake will be studied concurrently by three different systems, the choice of the instrument payload was made to be compatible with the appropriate deployment method and to cover as wide a range of instruments as possible. Three instrument payloads are therefore covered by matrices for operation with the space station, boom and subsatellites. A diagram of the appropriate instrument is included in Section 2.2 and the reference relates to a detailed description of the diagnostic.

2.4.1.4 Interface Support and Performance Requirements. The long periods of experimental study of the disturbed region may have a major impact on the spacecraft's support system. This fact when coupled to the large number of individual diagnostics that will be operating concurrently will produce a considerable total amount of data, a moderate power requirement and the necessity for strict control on spacecraft contamination of the environment. This long operational period will also necessitate a high degree of maintenance to the instruments in terms of repair, replacement and calibration requirements. The support requirements for the space station, booms and subsatellite are shown on Tables 2-11 through 2-13.

Although this investigation measures the artificial environment produced by the spacecraft, the measurements that are obtained will be dependent to a high degree on the local plasma conditions. The type of instrument that is used to measure a specific plasma parameter will therefore vary depending on the inclination and altitude of the space vehicle. The particular set of instruments described for this experiment are pertinent to the specified altitude of five hundred kilometers and an orbit inclination of 55°. The measurements of the induced environment will also depend on gaseous effluents ejected from the space vehicle, external support systems such as high power data transmission antennas and the non-uniformity of the space station surface due to the solar cell requirements. Although these items are not direct support requirements, the architects of the support systems must be aware of the effect their design can have

Table 2-11. Support Requirements for the Space Station

Parameter Under Study	Weight kg (lb)	Power Watts		Number of Instrm'ts	Thermal °K (°C) N = Normal S = Safe	Duration On	Data bps		Stability	Pointing
		Max	Min				Desirable	Min		
Electron Temperature	6(13)	12	2	4	263° to 313°N (-10° to +40°N) 243° to 333°S (-30° to +60°S)	As continuously as possible	10^4	10^3	1°/min	0.5°
Electron Density						~25% of the time	3×10^3	500		
Ion Temperature	6(13)	13	3	4	As above	As above	10^4	10^3	1°/min	0.5°
Ion Density							3×10^3	500		
Gas Analysis	8(18)	18	15	2	263° to 313°N (-10° to +40°N) 243° to 333°S (-30° to +60°S)	~15 sec/ analysis	10^3	300	1°/min	~5°

Table 2-12. Support Requirements for the Booms

Parameter Under Study	Weight Kg (lb)	Power Watts		Number Per Boom	Thermal °K (°C) N = Normal S = Safe	Duration On	Data bps		Stability	Pointing
		Max	Min				Desirable	Min		
Electron Temperature	1.5(3.3)	2	2	2 probes	263° to 323°N (−10° to +50°N) 243° to 343°S (−30° to +70°S)	As nearly continuous as possible	10^4	10^3	1°/min	±5°
Electron Density						~25% of the time	3×10^3	500		
Ion Temperature	2.5(5.5)	10	4	1	As above	As above	10^4	10^3	1°/min	±5°
Ion Density						As above	3×10^3	300		
Electric Fields A.C.	15(33)	20	15	1	As above	As above Each operates ~8 mins/orbit	10 MHz analog	Onboard tape recorder	1°/min	±5°
D.C.	30(66)	50	40	1	As above	As above	10^3	300	1°/min	±5°
Magnetic Field	1.5(3.3)	2	1	1	As above	As above continuously	10^3	10^3	1°/min	
Particle Flux Direction	1.5(3.3)	5	5	1	As above	As above	10^3	300	1°/min	1°

Table 2-13. Support Requirements for the Subsatellite

Parameter Under Study	Weight Kg (lb)	Power Watts		Number Per Satellite	Thermal °K (°C) N = Normal S = Safe	Duration On	Data bps		Stability	Pointing
		Max	Min				Desirable	Min		
Electron Density	2.5(5.5)	10	2	1	263° to 313°N (-10° to +40°N) 243° to 333°S (-30° to +60°S)	As nearly continuous as possible	10^4	500	1°/min	0.5°
Electron Temperature						~25% of the time	10^4	10^3	1°/min	0.5°
Ion Density	2.5(5.5)	10	3	1	As above	As above	10^4	500	1°/min	0.5°
Ion Temperature					As above	As above	10^4	10^3	1°/min	0.5°
Ion Mass Analysis	8(18)	18	15	1	As above	As above	10^3	300	1°/min	0.5°
Alfven Waves	3(66)	2	2	1	As above	As above	500	200	1°/min	0.5°
Supra-thermal Electrons	1.5(3.3)	5	5	1	As above	As above	10^4	10^3	1°/min	0.5°

on the success of the experiment. The manned requirements for this investigation will mainly be dependent on the amount of maintenance necessary on the instruments for the long duration of the measurements. The operation of the individual sensors will be highly automated, but some degree of manned participation in boom and subsatellite deployment and control is desirable. The necessary skills are, therefore, an electromechanical technician and a plasma physicist. With a skillful plasma physicist in control, the total duration of the observations can be reduced, since he can program the system to obtain samples over the full range of parameters.

2.4.1.5 Role of Man. It will be necessary for two highly trained people to conduct the observation program from the spacecraft while being guided by communication with the appropriate scientific investigators on the ground. The personnel most useful would be a physicist and an engineer. In general, the physicist would be responsible for the positioning of the various sensors, data examination and experimental decisions. The engineer would assemble the booms, attach the sensors and launch the subsatellites and inflatable objects. At the start of the experiment they will both check out the equipment and ascertain that the apparatus is functioning correctly. During the experiment, the scientist will monitor the various sensors with several multitrace oscilloscopes, and will make any corrections necessary. The engineer will launch the subsatellites and inflatable objects at the correct time and control the position of subsatellite and the alignment of the booms. At the conclusion of the experiment the engineer will recover the subsatellites and dismantle the boom while the scientist ensures the correct operation of the on-board data processing.

The expected time distribution for the involvement of man in the measurements will be at a maximum at the start. Here, a great deal of time will be spent monitoring and correcting malfunctions, but once the best configuration for the wake mapping has been achieved, only monitoring periods of several hours per day will be necessary. Due to the lack of experience in this mode of operation, it is to be expected that the mapping will be repeated under different ambient conditions. In any case, it may be necessary to obtain information for a period of approximately one year.

2.4.1.6 References

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2.4.2 INVESTIGATION OF PLASMA RESONANCES AND THEIR HARMONICS

2.4.1 Scientific or Technical Objective. The objective of this experimental group is to study the resonances stimulated in the ionosphere by topside sounder techniques.

The main resonances to be studied are at the electron plasma frequency, the upper hybrid frequency, and the electron cyclotron frequency and its harmonics which are very difficult to study in laboratory plasmas.

A considerable amount of work has already been carried out on plasma resonances in the laboratory and in their theoretical interpretation[1,2]. A complete understanding of the relationship of these theories to the observed space resonances has not yet been derived. There is, therefore, a need to conduct further, more detailed experiments in space on plasma resonances and to explain other observed phenomena associated with the resonances. These include remote resonances, plasma echoes, the proton period in the electron plasma resonance, low frequency resonances, and floating resonances. All the mentioned effects[3] have frequencies which are in the radio frequency portion of the spectrum. Another set of resonances in the VLF region associated with ion modes are also known to occur and, as VLF transmission and receiving equipment is proposed as part of the facility, future experiments in this resonance region are a natural extension to the study of resonance phenomena.

Another future objective of this experimental group would be to study the effect of irradiating the ambient plasma with very large amounts of RF power. This experiment may cause a slight elevation of plasma temperature which would, however, produce a significant change in plasma characteristics.

2.4.2.2 Description. The initial examinations in this area will investigate the plasma resonance phenomena already observed on the ISIS series of top side sounders. These resonances appeared as persistent signals, lasting several milliseconds at certain characteristic frequencies, after the transmission of a wide frequency range of one hundred microsecond pulses.

An improved transmitter design which can investigate these resonances in detail and provide the laboratory with a flexible system for other investigations has been proposed for the ISIS C satellite[4]. This transmitter has the capability of a wide range of operations. By making the transmitter frequency sweep and sweep rate identical to that of the receiver, the complete spectrum of plasma resonances can be produced, depending on the alignment of the antenna to the magnetic field. This mode is similar to the swept frequency transmissions of the Alouette satellites and enables quick identification of the resonances and a comparison of their strengths and durations. Furthermore, if the receiver is operated over a reduced frequency range which is centered about a particular resonance, the single resonance spike can be studied in detail, and by widening the pulse width an increase in frequency resolution can be obtained. Finally, if the transmitter sweep is reduced to zero, it becomes a fixed frequency transmitter enabling a study of harmonic spikes to be performed as the receiver is swept. This mode is similar to the system used on the Explorer XX top side sounder.

The antenna will most probably be boom mounted so as to remove it from the "noisy" environment of the space station, but if trouble is still experienced, the receiver can also be mounted on a subsatellite with its own antenna. This technique would also provide a measurement of the wave's group velocity and the integrated plasma density by observing the time-delay between the initiation of the pulse at the space vehicle's antenna and the observation at the subsatellite receiver. The main difficulties here would be in obtaining and preserving the degree of alignment necessary between the receiving antennas and the magnetic field, and in measuring the distance between the transmitting and receiving antennas. The long length of the antenna will cause a v x B (where v is the spacecraft velocity and B is the local magnetic field) potential to be developed across it. As the space station wake has been found to be sensitive to the potential[6] of external bodies, the antenna should be removed during the initial phase of the wake experiment measurements. In any case, the antenna should be isolated from the main facility and be capacitatively coupled to the transmitter and receiver.

The volume of plasma over which the resonance condition is integrated is at present unknown. Topside sounders have so far not observed any mode structure in the spectrum due to the wake "cavity" (Section 2.4.1) and the observed frequencies do not appear shifted or spread from the expected ambient plasma values. This condition may not be true for the space station where the wake is much larger.

The best initial mode of operation for the study of plasma resonances would, therefore, appear to be to use a boom-mounted antenna and the transmitter-receiver techniques suggested above. The resonances would be studied as a function of magnetic field alignment, transmitted power and plasma conditions. Then, a receiver and its antenna would be placed on board a subsatellite. The subsatellite would be oriented with respect to the local magnetic field as directed by the main facility. In this case, nearly continuous pulse transmissions are possible and a repeat of the above experiments can be conducted with the satellite at varying distances from the facility.

An interesting harmonic wave experiment which has provided an insight into the observed space resonance phenomena has been carried out at low harmonic numbers in the laboratory[7]. It would be possible to conduct this experiment under more precise conditions in space and to obtain a verification of the theory of electrostatic waves at wave numbers not easily accessible in the laboratory. Also, this technique could be developed as a precise method of measuring the electron temperature and density. Initial studies could be carried out in the local undisturbed plasma and also in the wake region. The latter study may be difficult since a Maxwellian distribution is required in order to obtain electron temperatures from the measured transmission time. Because existing experimental results in the wake region indicate that deviations from this distribution do occur, measurements in the wake region may be inaccurate. The minimum wake dimension with respect to the main facility is not well defined, but is thought to be of the order of several tens of meters. If this is found to be correct, boom mounting of the experiment may not be adequate to place the antenna in the ambient plasma, and mounting on a subsatellite may be necessary. However, an array of diagnostics mounted on a boom or a satellite could determine the degree of deviation from the Maxwellian distribution as well as provide a check to the measured values of plasma density and temperature.

The experiment requires two parallel antennas approximately 20 meters long and 13 meters apart. An electrostatic wave is generated by applying an RF pulse to one antenna. This wave travels through the plasma from the transmitting to the receiving antenna at a velocity of about 1.29 times the electron thermal velocity. From the time delay between transmission and reception of the signal, the waves' group velocity can be determined. By sweeping the radio frequency, one can explore the dispersion relations of the waves and derive electron temperature and density from these relationships. The orientation of the plane of the antenna is very important, as the cyclotron harmonic waves are probably highly damped in non-perpendicular directions to the magnetic field, whereas the hybrid resonance requires the antenna plane to be parallel.

In both of the discussed experiments the magnitude and direction of the magnetic field needs to be accurately known, and will be determined with the fluxgate magnetometers described in the wake instrument description. Also, in the case where separate receiving and transmitting antennas are used, the velocity of the antenna relative to the wave can introduce an appreciable error. This error can be removed if the receiving antenna is used only as a reflector to send the ray back over its initial path and the relative velocity between the two antennas is kept constant.

2.4.2.3 Observation/Measurement Program. The plasma resonance program is essentially divided into two portions which are shown on Table 2-14. One of these is a direct study of the plasma resonances and their harmonics, utilizing the technique developed on the ISIS program. The other is a detailed examination of a wave transmission characteristic that may develop into a useful plasma diagnostic tool.

The former program will observe the effect of stimulating resonances in the ambient plasma over the radio frequency spectrum of 100 kHz to 200 MHz. Initially, the resonating frequency for each plasma natural resonance will be determined using a swept frequency mode with the transmitter and receiver locked together. Then, the measured

Table 2-14. Observation/Measurement Program

	Subject Measured	Frequency Range	Frequency of Measurement	Length of Measurement Period	Pulse Power	Pulse Width
Harmonic Resonances Transmitter Antenna	Resonances of Long Duration Compared with the Signal	0.1 - 20 MHz	once/orbit	15 mins/orbit	~500 watts	~100 μs
Transmission Experiments	Transmission Time Delay	0.1 - 20 MHz	once/orbit	15 mins/orbit 200 measurements	150 watts	100 μs

value of the natural plasma, hybrid and cyclotron frequencies will each be transmitted at their particular fixed frequency successively, while the receiver is still being swept over the complete range. In this manner, the conditions under which the harmonic frequencies of each fundamental value are generated can be investigated. The detailed structure of the resonances can be then observed by limiting the receiver sweep to a narrow range centered about a resonance value. The resonances also will be studied as a function of the local plasma parameters antenna alignment with the magnetic field and transmitted power. Initially, due to the amount of data generated and perhaps power limitations, the experiment could be operational for 10-15 percent of the orbit period. The receiving antenna will also be the transmitting antenna during non-transmitting periods, with a separate antenna mounted on a maneuverable subsatellite. This second antenna will investigate wave transmission velocity and the extent of the resonance volume; therefore, its position relative to the space station will need to be accurately known.

The second of the two main experiments will determine wave transmission characteristics and will utilize two dipole antennas separated by a fixed distance. Both antennas will be capable of operating in the receiving and transmitting mode. The ideal operating position of this experiment is on the remote satellite, so that the wake and the ambient plasma regions can be both investigated. This mode of operation may also be necessary due to the expected noisy environment of the space vehicle. One of the antennas will be pulsed at different frequencies over the same range as before, and the time required for the wave packet to reach the receiving antenna will be measured. From this time, and an accurate knowledge of the path length, the group velocity of the wave can be calculated. Also, the dispersion relations of the waves and the electron density and temperature can be determined.

2.4.2.4 Interface, Support and Performance Requirements. The initial experimental period of this study does not impose any major demands on interface and support requirements. The requirements, shown on Table 2-15, are for short duration investigations requiring only medium power support with relatively light data loading. In the instances where the receiving antenna is separated from the main laboratory by deploying on a subsatellite, the alignment of the antenna with respect to the magnetic field will be a critical factor. The data can be processed by an onboard computer or stored on tape for delayed transfer or bulk transfer. An ideal monitoring system would be an onboard spectrum analyzer which would provide a visual indication of the resonances and their harmonics to the physicist and a processed output for the computer. Future studies may investigate the effect of plasma resonance heating of the ambient plasma. In this instance, power requirements in the order of tens of kilowatts for several seconds may be desirable, together with a diagnostic subsatellite to investigate the heated plasma region.

2.4.2.5 Potential Role of Man. The required personnel in this experiment are a physicist and an electromechanical technician. The technician will deploy the boom with a RF cross dipole antenna and orient it from within the facility with respect

Table 2-15. Interface, Support and Performance Requirements

Apparatus	Power	Thermal Control °K (°C)	Inclusion On Space Station	Inclusion On Sub Satellite	Data Desirable/ Minimum	Pointing	Stabilization
Harmonic Resonance Experiment	500 watts	223° to 343° (-50° to +70°)	Transmitter Yes	Transmitter No	7×10^5 b/s	N/A	N/A
Antenna		223° to 343° (-50° to +70°)	Yes	Yes		<1°	<1°/min
Transmission Experiment ------------ Transmitter Antenna	~150	223° to 313° (-50° to +40°)	Yes Yes	No Yes	7×10^5 b/s	<1°B <1°/4° Between Antenna	<1°/4 min

to the magnetic field, as initially required. The transmitter-receiver will then be checked out by the physicist and transmission will be initiated after any necessary corrections have been completed.

Initially, the mode will probably be swept frequency changing to fixed frequency, as described for detailed examination. As effects can last in the region of a minute, the physicist will be able to judge when this is required. Besides a saving on the amount of unnecessary data, this mode of operation is important in the observation of unusual effects. These effects can be photographed with a polaroid camera after placing on the screen of a storage oscilloscope for study later. The antenna orientation with respect to the field will be changed and monitored by the technician who will also ensure the operation of the data recording system. Transmitter power will also be varied at the completion of the measurements; the technician will recover the antenna and, with the physicist, check out the accumulated data. Selected portions of the data will be analyzed by on-board spectrum analyzers, again saving on data transmission.

Essentially the same procedure will be adopted for the harmonic transmission experiment and in the operation of the extension experiments using subsatellites, as already described. The work load with time function will be nearly constant as measurements can be in all the experiments in very short times. Therefore, the majority of the time will be spent in changing the orientation of the antennas and in the setting up of the equipment for making measurements.

2.4.2.6 References

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2.4.3 INVESTIGATION OF WAVE-PARTICLE INTERACTIONS WITH VLF

2.4.3.1 Scientific and Technical Objectives. The scientific objective of this experimental group is to study the interactions of transmitted very low frequency electromagnetic waves with both naturally occurring and artificially produced particles. Studies also will be carried out on wave propagation in the magnetosphere at various wave-normal angles with respect to the magnetic field and on emissions stimulated by the transmitted waves.

The interaction between VLF waves and energetic particles trapped in the magnetospheric field is thought to be a major process by which the particle populations in the various L-shells are controlled. Various theories[1,2,3] have been proposed and are based on the transverse resonance condition between waves and particles. One of these theories[1] depends primarily on particles in cyclotron resonance whose velocity parallel to the field line Doppler shift the VLF wave frequency to their cyclotron frequency. The pitch angles of these particles are altered and wave growth occurs when the pitch angles become sufficiently anisotropic. The magnitude of the growth rate is determined both by the pitch angle anisotropy and the number of particles in resonance. This number adjusts by balancing acceleration with precipitation so that the growth rate exactly replaces the escaping wave energy. Therefore, there is an upper limit to stably trapped particle fluxes. Another resonance condition that can occur is when the wave normal is nearly perpendicular to the magnetic field line. In this case, the electric vector of the wave is orientated along the field line. This field tends to be shorted out due to high conductivity that exists, but triggered magnetospherically reflected whistlers are thought to be examples of this resonance condition. An experimental study of the various proposed wave-particle interaction theories is therefore an area in which study is necessary.

The technical objectives include the study of very long antenna deployment from the spacecraft and the antenna mechanical stability as a function of diameter and length.

Especially important is an investigation into the occurrence of nonlinear plasma effects in the immediate vicinity of the antenna.

2.4.3.2 Description. Magnetospheric waves can be artificially produced by transmitting VLF from the ground along ducts of electron enhancement. These waves have normals with an approximately zero angle with respect to the field line and resonate with naturally trapped electrons moving at 180° to the field line in a transverse resonance mode. Waves transmitted from a spacecraft can have the complete spectrum of wave-normal angles and can therefore produce the longitudinal resonance mode in addition to that of the transverse resonance.

The coupling of the VLF waves to the ionospheric absorption is not well understood, but estimates indicate that to achieve naturally occurring intensities, at reasonable distances, up to tens of kilowatts of power may be necessary. If large amounts of radiated power can be achieved, large scale changes in particle pitch angle distributions of trapped particles can be made, which may ultimately lead to artificial control of the particle populations in the shells.

It is easier to produce pitch angle scattering for electrons than for protons, therefore, initial studies will be restricted to the electron resonances. The desirable equipment on the spacecraft to examine these wave particle interactions will be a VLF transmitter[4] with a frequency range of 500 Hz to 100 kHz which can operate in a swept or fixed frequency mode with a controllable power up to 10 kw of peak power. A cross dipole antenna[4], whose plane can be oriented with respect to the magnetic field line will be used for transmission. The receiving antenna[4] will be of a loop configuration coupled to narrow and broad band receivers[4] for detailed studies of waves. Both antennas will be placed as far away from the space station noise and from each other as possible. It may be necessary for the receiver to be placed on a subsatellite together with the RF experiment receiver. This arrangement is especially important if dc-dc converters on the space station are operated in the VLF range. Electron detectors with an energy response from 100 eV - 500 keV[4] will be placed on the outside of the space station. These detectors will be positioned so as to cover a wide range of angles with respect to the field lines. The subsatellite will be equipped with the same instruments as the space laboratory, except for the transmitter and dipole antenna array. Suitable VLF ground based transmitter stations can provide useful back up to the space laboratory. Here, the operational frequency range will be 10 Hz to 100 kHz over a wide range of power levels. The upper limit of 100 kHz is the required frequency for transverse resonance with a 500 keV electron on the L = 1.7 shell.

Wave-particle interactions in the L = 2 to 6 shells will be possible for a maximum of about 30 minutes per orbit or for a period of about eight hours per day. Changes in particle pitch angle and wave intensity can be observed more easily in this region, as the level of activity is reasonably constant. The transmitter will be operated in a pulsed, swept frequency mode at different power levels with possibly a change in the wave normal angle on each orbit. The resulting change in pitch angle distribution, wave delay and spectral variations will be observed either on the space station, the subsatellite or a ground station. Wave propagation from ground stations should be able to produce observable transverse resonance effects if enough power is available. This mode can therefore be studied by a passive space station or subsatellite when in the appropriate region. Future wave-particle interaction studies could attempt to observe proton pitch angle changes and the interaction of waves with artificially-produced particle beams.

Other experimental studies that can be attempted from the space station involve ducted and non-ducted propagation. Ducted studies include the monitoring of the plasma-pause boundary from the space laboratory by the observation of continuously transmitted signals from a ground station which is in the L = 4 region. Also, information can be obtained on duct dimensions by transmitting waves from the space laboratory with small wave normal angles along the field lines. The time delay between the transmission of the wave and any received echo can provide information on duct length. This time delay together with a knowledge of magnetic field direction and spacecraft velocity can also indicate the size of the duct width.

The stimulation of naturally observed VLF emissions by transmitting various frequencies from the space laboratory with small wave normal angles with respect to the magnetic field would be an interesting experiment. This is especially true for the stimulations initiated at half the minimum gyro frequency on the field line[5]. Stimulated emissions caused by non-ducted waves are also of interest, especially in the region of the so-called lower hybrid frequency noise. Variation in transmitter power, pulse length, repetition period and frequency sweep rate will be necessary to acquire information regarding the mechanism of stimulation. Initial studies on the possibility of VLF communication from spacecraft could also be attempted. As already mentioned, it is suggested[6] that propagation of waves in the magnetosphere may not be possible below the local ion plasma frequency, therefore investigations in this region are of interest and could have important consequences.

The technical investigations will be concerned with the deployment of long antennas and the study of antenna radiation patterns. This latter problem could be carried out by measuring the antenna current distribution and measurement of the electric field at various angles to the antenna as a function of transmitted power.

2.4.3.3 Observation/Measurement Program. The proposed orbit of 55° inclination and altitude of 500 km will limit the coverage of the L-shells 2 to 6 to about thirty minutes per orbit (see Table 2-16). Furthermore, for high power transmission, unless some form of generator is available, operation will be limited to about once per day. The measurement of wave-particle interactions will therefore be limited, if using batteries, to several one-second bursts of transmitted VLF over a thirty-minute period, once per day. Observation of stimulated VLF waves over the frequency range of one to a hundred kilohertz will be made during the bursts, together with any changes

Table 2-16. Observation/Measurement Program

	Subject Measured	Frequency Range	Frequency of Measurement	Length of Measurement
Transmitter	N/A	500 Hz to 100 kHz	Once/Orbit	Several pulses of 1 sec duration
Receivers a) Electric dipole b) Magnetic loop	VLF Electric Vector Magnetic Vector	0.1 to 100 kHz	Once/Orbit	For a period up to 30 mins depending on the orbit
Particle Detectors a) 0-2 keV b) 0-5-20 keV c) 20-500 keV	Accelerated Electrons	N/A	Once/Orbit	As above
Magnetometer	Magnetic Field	DC	Once/Orbit	As above

in the electron pitch angle distribution. The particular electron energy affected by the wave will be related to the frequency and the orientation of the wave normal.

2.4.3.4 Interface, Support and Performance Requirements. The support requirements for this experiment will exert a major impact on the resources of the space vehicle (see Table 2-17). The power estimated to be required to produce appreciable wave particle interaction processes is on the order of one to ten kilowatts of peak power. As battery supplies are the probable power source, the experiments will be limited to several one-second bursts of transmission once per day. The data requirement, although quite large, will be easily accommodated due to the short period of operation by storage and data transfer during non-operating periods. Another area in which problems may occur is related to the large VLF antenna. Major items here are the method of deployment and stability and the plotting of the radiation pattern of the antenna. This last item could possibly be carried out by EVA, but due to the difficulties involved, a better method would appear to be some form of boom-deployed sensor.

The experiments which can be carried out using VLF propagation are determined by the orbit of the spacecraft. Wave-particle interaction processes require long periods in high L shell values; whereas a study of magnetospheric reflection requires an orbit near the equator. Also, ducted studies would ideally be carried out in an orbit which

Table 2-17. Interface, Support and Performance Requirements

Apparatus	Power Watts	Point-ing	Stabili-zation	Thermal Control °K (°C)	Inclusion on: Space Station	Inclusion on: Subsat	Remarks	Data Requirements: Req'd	Data Requirements: Min
Transmitter	Up to 10 kw peak power for up to 15 min/orbit/day 0.2% duty cycle	N/A	N/A	273° to 313° (0° to 40°)	Yes	No	Power by: a) solar cells b) hydrazine turbo alternator		
Transmitting Antenna	N/A	± 2°	1°/min	253° to 313° (-20° to 40°)	Yes	No	Stem, or possibly inflatable		
Receiving Antenna a) Electric dipole b) Magnetic loop	N/A	± 2° ± 2°	1°/min	253° to 313° (-20° to 40°)	Yes	Yes	Boom-mounted transformer. Coupled to receivers isolated s/c	Video tape 500 kHz Analog	tape only
Particle Detectors a) 0 - 2 keV b) 0.5 - 20 keV c) 10 keV - 500 keV	2 watts 4 watts 1 watt	± 1° ± 1° ± 1°	1°/min 1°/min 1°/min	273° to 313° (0° to 40°)	Yes	Yes	Retarding potential analyzer. Electrostatic hemispherical analyzer. Scintillation spectrometer.	12 channels 6 for each group - 3 kB 3 kB 3 kB	 1 kB 1 kB 1 kB

Table 2-17. Interface, Support and Performance Requirements, Contd

Apparatus	Power Watts	Point-ing	Stabili-zation	Thermal Control °K (°C)	Inclusion on		Remarks	Data Requirements	
					Space Station	Subsat		Req'd	Min
Electronic Receivers	20 watts	N/A	N/A	273° to 313° (0° to 40°)	?	Yes			N/A
Fluxgate Magnetometer		N/A	N/A	273° to 313° (0° to 40°)	Yes	Yes			

spends long periods travelling along VLF ducts. The proposed orbit of 55° inclination and 500 km altitudes is therefore poor for ducted and magnetospheric reflection studies, but wave particle interaction studies are possible. The scope of this orbit for VLF propagation studies can be improved with the use of a conjugate satellite; this would remove to some degree the requirement of specific positioning of the spacecraft.

2.4.3.5 Potential Role of Man. The personnel required to conduct this experiment are a physicist familiar with VLF propagation, and an electromechanical engineer. Initially, they would both assemble the dipole antenna and deploy it from the spacecraft. The engineer would then measure the antenna current distribution and the electric field at various angles with respect to the antenna. The loop antenna would be deployed and the position where the minimum interference from the space station occurred would be determined.

The transmitter and particle detectors would be checked out and the latter may be changed perhaps by EVA. The physicist would study the detected VLF waves and particles and program the transmitter mode of operation. The engineer would monitor the antenna stability and transmitter output power as a function of position in the magnetosphere.

At the end of the experiment they would both monitor the data for validity and discuss the next experimental phase with the ground based investigators. Removal of the antenna for storage and replacement with a different configuration may also be required at various times.

2.4.3.6 References

Reference No.	Reference
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2.4.4 INVESTIGATION OF ELECTRON AND ION BEAM PROPAGATION

2.4.4.1 Scientific and Technical Objectives. The objective of this experimental program is to use energetic particle beams to obtain information on the space environment. These studies can be either in the form of passive tracer techniques or active experiments where the particles induce natural processes to occur. At present, development of particle beams suitable for space operation is underway. The main experimentation to date has been with simple electron beam devices[1,2], but more elaborate systems have reached the design stage[3]. Although ion beam technology has reached a high degree of sophistication for laboratory use, the only space systems are those developed for ion propulsion systems. These, however, are ideal for conversion to high-current, relatively low-energy ion accelerators.

2.4.4.2 Description. Particle beams can be used in two major configurations for the study of the space environment. One of these is in the form of a passive tracer element where relatively low fluxes of energetic particles can be used to study electric and magnetic field structure, particle drift processes, etc. The other configuration is an active one where the injected particles dominate the region and are used as devices for providing controlled modifications of the plasma itself. Examples of these active roles are the triggering of processes concerned with auroral precipitation, belt particle population control and beam plasma instabilities.

Due to the different demands in terms of particle beam requirements for these various investigations, the main operational description will deal with one topic; the tracer study of the geomagnetic field. In order to investigate this particular characteristic, the particle beam is used as a tracer and therefore, ideally, must not cause collective interactions with the local plasma through which it passes. As beam plasma instabilities are often critically dependent on particle flux, a relatively low flux is therefore required. However, due to the difficulties in detection of a beam at a large distance from its source, a fairly substantial flux may be necessary. There appear to be two feasible methods of determining the path of the beam. One of these methods is by the direct measurement of the energetic particles; this requires a large diameter beam with a high particle flux and a large group of detecting satellites. The second method involves some form of measurable beam interaction process, such as the production of artificial auroral rays or the stimulated emissions from alkali metal ions due to artificial or solar excitation. These processes, therefore, require a small-diameter, high-intensity beam monitored by ground and/or satellite optical systems. The direct detection of the beam appears to be difficult and extremely expensive, therefore, only the beam interaction process will be considered.

The use of artificial auroral rays to obtain information on magnetospheric structure has been under consideration for several years[1]. Since an aurora is caused by the ionization and molecular excitation of the air molecules and atoms by energetic particles as they dissipate their energy in the upper atmosphere, the proposed technique is to inject energized particles at a specified angle with respect to the field lines upwards from a space vehicle which is at an altitude of 200 km or above. If the field line is closed, the particles travel to their conjugate position in the other hemisphere where some of them will interact with the atmosphere and form an aurora ray. If the injection angle is sufficiently large, the majority of the particles will be reflected (First Adiabatic Invariant) and will form another ray in the atmosphere below the original injection vehicle. If the coordinates of the injection vehicle are exactly known and the auroral rays are photographed at night by some form of ground and space vehicle based sensitive TV system, several magnetospheric parameters can be determined. From the parallel velocity of the beam and its transit time, the length of the field line can be calculated. Conjugate points can be determined to an accuracy of about 1 km, which is nearly two orders of magnitude better than experimentally possible at present. These measurements would also determine the accuracy of the theoretical computations on field line length and conjugate positions that have been made. Variations in the experimental measurements of field line length and conjugate position can occur due to temporal changes in the parameters that determine the beams path. These are caused by the appearance of perpendicular and parallel electric field and due to magnetic field line curvature and motion. Furthermore, if the ejection angle in the northern hemisphere is kept constant, a large loss of particles to the atmosphere in the reflection region can occur on some field lines due to the South Atlantic anomaly. In addition to the length and conjugate point determination, estimates can be made on whether field lines have open or closed geometry by the ability of the particle beam to form auroral rays.

In general, for any of these measurements to be made, the space vehicle's location would have to be precisely known. Also, due to the power that is required to produce visible auroral rays, 1 to 10 kw peak power for about a second, the accelerator will be limited to several one second operations. Therefore, an experimental period would be limited to about a ten-minute period once per day. The field lines that could be examined with the proposed orbit of 500 km and 55° inclination, extend out to about L = 6, which includes the plasma pause boundary region. Furthermore, to obtain the maximum value from the abundant ground stations in the northern hemisphere, the ejection of the particle beam should be up the field line from the southern hemisphere. This mode of operation can be improved if a satellite equipped with a sensitive TV system can be positioned at approximately the conjugate point of the space station.

The ability of a particle beam to produce a visible auroral form depends on the particles total luminous efficiency from several processes. The luminous efficiency for electrons is well known and has a maximum at an energy of about 10 keV, whereas the ion luminous efficiency is an unknown quantity. The present experimental investigations, therefore, are being pursued with electron beams although some advantage may be gained with the use of ions due to the lower particle losses from possible wave-particle interactions.

Two experiments using electron beams have so far been carried out in space[1,2]. They have demonstrated the ability of an intense electron beam to produce a narrow auroral ray, and for a low intensity beam to be propagated from one hemisphere to the other and be reflected back to its origin. What still needs to be determined is, whether a flux of electrons of an intensity sufficient to produce a photographable auroral ray can be propagated without major loss, and in a manner similar to that already demonstrated. If this experiment can be achieved, the use of electron beams for studies in conjunction with the space station would be a major candidate for the initial program.

The other technique of monitoring optical emission from ions excited by the sun, to determine the particle beam path is theoretically most promising. The most suitable particle for this experiment appears to be low energy ~5 keV alkali metal ions. This selection is due to the alkali metal's bright emission lines and the need for the velocity of the ion along the line to be much greater than any perpendicular velocity produced by local electric fields. No appropriate alkali ion engine exists, but it has been suggested[4] that the conversion of existing ion engines to alkali metal use is possible. If the mode of operation outlined for the auroral spot method is used, the advantage of the alkali metal ion beam over the electron is the observation of the complete path of the beam as observed against a night sky. Unfortunately the errors due to steady and fluctuating electric and magnetic fields are still present. Although this technique appears promising, the only practical indication of its feasibility is the success of barium cloud techniques[5] in the determination of electric fields in space.

A serious difficulty arises when charged particle beams are fired from spacecraft due to the change in electric potential that will occur on the body's surface. Besides the interference with the ejected beam, large changes in the wake characteristic can occur (see Section 2.4.1) complicating the measurements of the ambient plasma conditions. This problem is especially severe at high altitudes where the necessary current balance cannot be obtained from the environment. For the proposed low altitude orbit, the problem is still present for a lone physics module. For currents much greater than an ampere, at an electron energy of 10 keV, an order of magnitude increase in the collection area will be necessary. This can possibly be accomplished by the deployment of an aluminized sail as was used on the Aerobee flight. Another possibility is the ejection of a dense plasma or a positive particle beam at the same time as the electron beam, the latter of which appears to be the more attractive.

2.4.4.3 Observation/Measurement Program. The operational period of this experimental group will be governed by the space station power supply (see Table 2-18). With the conventional battery power supplies (see Table 2-6) the period of operation will be of the order of one minute once per day, with about a 25 percent duty cycle. Initially, so that the auroral rays may be easily detected, ten, high-current pulses with a 50 percent duty cycle will be fired followed by single bursts on a 20 percent duty cycle until a loss of power occurs. Observation of the auroral ray with ground-based and conjugate satellite sensitive electro-optical systems will be attempted,

Table 2-18. Observation/Measurement Program

Apparatus	Position of Apparatus	Subject Viewed or Measured	Range	Operating or Observation Period	Number of Observations	Reference Section 2.2
Accelerator	Space Station	N/A	0.1 - 5 amps 10 - 20 kV	1 min 50% working	Ideal is once per orbit, but due to power limitations, once per day	Table 2-6
Hemispherical Analyzers	Subsatellite and Space Station 6 analyzers over 180°	Particle flux	10^9 - 10^2 electrons/cm^2/sec	15 mins to 5 mins	Once per day	Figure 2-15
TV System	Subsatellite and Space Station	Artificial Aurora	300 - 3 Kilo Rayleighs	15 mins to 5 mins	Once per day	Section 1.4.1.2.1.3
Electromagnetic Receiver	Subsatellite and Space Station	E.M. Waves	100 kHz to 20 MHz	15 mins to 5 mins	Once per day	Table 2-3

together with observation of reflected rays by the space station. In conjunction with the auroral ray observation, a study of the particle beam energy spectrum and angular distribution will be attempted from the space station and satellite. The total observation period should last approximately fifteen minutes/day, which does not include the initial warm up period.

2.4.4.4 Interface, Support and Performance Requirements. The major long term support requirement for this experiment is in terms of the total level of power that can be supplied by the space laboratory system (see Table 2-19). Initial investigations will require nominal average power although power requirements are expected to grow as the investigation becomes more sophisticated. The probable initial experimental mode will be the electron beam study of the geometry of the geomagnetic field. The use of a generator on the space vehicle would improve the power supply but would probably result in an increase in noise, vibration and contamination of the environment from its exhaust.

A substantial portion of the accelerator system, including the high voltage generator, could be mounted external to the space vehicle thus decreasing the equipment volume and the high voltage hazard. The only part of the system internal to laboratory would be the batteries, control console and data collection systems. Stabilization of the accelerator platform has a maximum requirement of about one degree per minute, but this requirement could be removed if a magnetic deflection system was used to vary the beam injection angle.

The data requirements will be for eight, high-data rate digital channels, with two channels for the accelerator and six for the TV system and VLF measurements. The analogue channels will require approximately one megahertz bandwidth for data transmission, but storage on tape for transmission at an appropriate time is quite adequate. The digital channels will require approximately a three-millisecond time resolution with a word of eight-bit accuracy for a total period of about forty-five minutes per day. The minimum requirement is for about a 20-millisecond resolution of six-bit accuracy for five channels. General housekeeping channels will also be necessary but at low data rates.

The operation periods will require an environment that is free of local regions of high gas pressure and sources of ionization in order to reduce the possibility of high voltage discharges. Furthermore, some form of return current system to reduce charging of the space vehicle may be necessary during accelerator operation. This system could be either in the form of an artificial increase in vehicle surface area or in an increase in the local plasma density.

2.4.4.5 Potential Role of Man. High voltage accelerator systems and their associated equipment generally require a high level of maintenance and repair to achieve a satisfactory standard of operation. This may be especially relevant to space

Table 2-19. Interface, Support and Performance Requirements

	Power Watts	Volume meters^3 (ft^3)	Pointing	Stabilization	Thermal Control °K (°C)	Orbit	Special Prelaunch Requirements	Unique Requirements	Crew Support	Data Format	
										Required	Minimum
Accelerator	130 charging	0.28 (10)	± 1° ordinary ± 1° reflected beam	± 1°/min ordinary ± 1°/min reflected beam	Stored 273° to 333° (0° to 60°) Operational 283° to 303° (10° to 30°)	500 km alt. 55° inc.	Check out accelerator using portable vacuum system	Will not operate in high gas leakage environment. Return current collection.	Two man hours per operation	2 Channels each 5×10^5 bits per operation	10^4 bits per operation
Hemispherical Analyzers	5 operational	3×10^{-2} (1)	± 1°	± 1°/min	Stored 273° to 333° (0° to 60°) Operational 283° to 303° (10° to 30°)	500 km alt. 55° inc.	None	None	Three man hours per operation	6 Channels satellite. 6 channels Space Station 5×10^5 bits per operation	10^4 bits per operation
TV System	100 watts operational	1.4×10^{-1} (5)	± 1°	±1°/min	Stored 273° to 333° (0° to 60°) Operational 283° to 303° (10° to 30°)	500 km alt. 55° inc.	None	Operate against night sky	Three man hours per operation	Video tape recorder and band-width 1 MHz	Video record only
Wave Detectors	Already in use, see VLF & resonance experiment	As in VLF group	± 1°	± 1°/min	Stored 273° to 333° (0° to 60°) Operational 283° to 303° (10° to 30°)	500 km alt. 55° inc.	None	None	1/2 man hour per operation	5×10^5 bits per operation	10^4 bits per operation
Magnetic Field Direction & Magnitude	Already in use, see Wake	As in Wake Group					None	None			

vehicle operation where the local environment may be contaminated by effluents from support systems producing regions of high gas pressure and ionization. The participation of man in this group, therefore, appears necessary if the accelerator is to be at all reliable over a long period of time.

The initial assembly of the accelerator and its high voltage equipment will be performed by a physicist and an electromechanical technician inside the space laboratory. The accelerator system will then be deployed through an airlock onto a platform with at least two degrees of freedom outside the space station. This mode of operation is also required for the TV system, but the platform will be separate from that of the accelerator. After installation, the physicist and technician will calibrate and check out the accelerator characteristics over its complete operational range. Any particle detectors that are required will be deployed and checked out and the accelerator programming system will be tested. The experimental procedure will be as follows: The physicist will program the accelerator for a specific experimental mode. The warm up and test period prior to the actual firing will be monitored by the technician who will override the command system if operation is not satisfactory. In the event of a successful checkout he will monitor the accelerator operation while the physicist will monitor the detectors for their expected responses and make any alterations, if feasible. The data obtained will be checked for scientific value and the results will be discussed with the investigator on the ground. After each operation, the batteries will be charged and any faults that have developed during the experiment will be corrected before renewal of operation.

2.4.4.6 References

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2.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

The general intent of this FPE is to conduct experiments that actively perturb the ambient plasma conditions. These perturbations are directed at dominating naturally-occurring processes which are thought to control the space environment. In order to achieve this objective, one of the main controlling factors appears to be the level of power that will be provided by the space laboratory. All the experiments, except for the one examining wake phenomena, may at times require kilowatts of peak power per second of operation. The various experimental periods will be limited to a few minutes of operation per day if conventional battery supplies are the only power source. This has a profound effect on the other major support and interface requirements, resulting in no unusual system demands.

The data requirements for the experiments are high, but due to the short period of operation do not represent a serious restriction. However this does not apply to the wake experiment which will operate at relatively high data rates for long periods of time. The pointing and stabilization requirements are not particularly severe for any of the proposed experiment, the most stringent are those stipulated for the harmonic wave transmission experiment. The total weight and volume of the equipment required to permit the four experiment areas to be investigated represents an initial minimum requirement. At this stage of the study no effort to summarize the amount of monitoring and data processing equipment that may be required has been made. This will be done when the experiments reach a greater degree of definition and the amount of possible manned participation has been clarified. The amount of crew support that has been designated is a minimum level if man is to provide any degree of experiment monitoring, planning and data analysis. As already stated in the experimental section, manned participation could be especially valuable in increasing the amount of valid scientific data that could be obtained from this program.

Satellites may be used in conjunction with each of the experiments. In the case of the wake experiment, this preferably consists of several maneuverable subsatellites, one of which will monitor the ambient plasma and the remainder will investigate the far wake extent and characteristics. One of these subsatellites can also carry RF receivers and antennas suitable for conducting the studies outlined for the harmonic resonance group of experiments. The particle beam and VLF experimental groups use satellites that can operate in regions far removed from the space station and could, therefore, be launched from the ground, but would ideally require some form of maneuvering capability. These units need to be positioned along the particular L shell under investigation and at the conjugate position of the space laboratory.

The summary data on Table 2-20 represents, in the best judgment of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary, but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

2.6 POTENTIAL MODE OF OPERATION

The proposed space laboratory will enable a variety of disciplines to perform experiments in conditions that are extremely difficult to duplicate on earth. Plasma physics falls into this general category, but also has the added advantage of actually studying

Table 2-20. FPE Interface, Support and Performance Requirements

FPE	Mass (Weight) kg (lb)	Volume m^3 (ft^3)	Power kW	Crew Skills	Data Rate kbs	Logistics 30-day Avg kg/(lb) Up	Logistics 30-day Avg kg/(lb) Down	Pointing Accuracy	Stability	Altitude & Inclination Desired	Altitude & Inclination Acceptable	Unique Environmental Requirements	Remarks
Plasma	550(4) (1210)	1.4(4) (50)	0.3	6, 12	3.1×10^3 Plus Video Recording	11 (24)	11 (24)	±8 mrad (±0.5°)	0.4 mrad/min (0.025°/min)	>185 km (100 n.mi.) Polar	>50°	Minimum contamination	Not including subsatellites

the environment of the laboratory. It is therefore amenable to practically any structural form and designated orbit that the laboratory may take. In the case of the various proposed methods of operation, Shuttle, Experimental Module, or Integral Space Station, each of these modes can be used to advantage.

The wake study will investigate the various forms that the laboratory may take, especially if they progress from a lone module to the integral space station. This will provide an interesting experimental check on the theoretical predictions on the effect of size and shape on the wake characteristics. Furthermore, the changes in wake volume that will occur are also important items of the effect that they have on harmonic resonance phenomena. The free flying module configuration may limit the VLF and ion beam studies to short periods of operation if there is low power capability. However, it will provide an adequate form for the initial experimental program that has been outlined. With the probable integration of the module into a space station, with a suitable increase in power capability these experiments will have developed by then into a phase where much higher power levels are required. Therefore, in the case of the wake experiment, a projected mode of operation is from the free flying module to the space shuttle and finally the integrated laboratory. The initial mode is therefore suitable for extended stay time revisited by shuttle culminating in extended stay time using the space station. The other three experiments also appear to profit from this operational progression but could also initially utilize the limited on-orbit stay time as with shuttle. In this instance it is due to the fact that they are active experiments and therefore initially are more ideally studied when isolated, in order to ascertain their effect on the laboratory itself. This ranges from the electrostatic charging of the body to the effect of deploying large antennas and satellites.

In addition to the consequences that the laboratory size, shape, and configuration may have on the experiment, the proposed different operational periods also influence the experimental procedure. The wake experiment requires long periods of observation and therefore will need extended on-orbit stay time in an operational mode. This could be accomplished by a completely automated laboratory, but all three areas of the wake ideally need to be investigated concurrently. This would be difficult, as refueling and docking of the subsatellites investigation the far wake appears to be an extremely difficult task to automate successfully and safely at this stage. A compromise might be to conduct an automated study of the wake out to about five space laboratory radii for any long periods of non-manned stay and conducting the far wake studies only during man's presence. The other three experiments are limited to short operational periods and therefore can initially operate adequately with limited on-orbit stay times. Ultimately, however, long periods of operation from a laboratory with a high support capability will be required.

In conclusion it appears that an initial experimental mode could be a lone module operating with a high degree of automation visited frequently by man for maintenance, repair and data study. The module could also be useful to conduct specific experiments in conjunction with the shuttle. This would ultimately progress into a full space station with long periods of manned participation in the experiments that would conduct major environmental[4] perturbation studies.

2.7 ROLE OF MAN

The participation of man in the proposed experimental program will be especially valuable in the areas of the general setting up of the experimental apparatus, monitoring of experimental procedure, equipment maintenance and repair and data analysis. For the initial experiments to be conducted from the laboratory it will be possible to program and decide on the most desirable format for the apparatus while the laboratory is on the ground. However, it will be necessary for a large amount of the apparatus to be deployed, checked out and calibrated once the laboratory is positioned in the desired orbit. This will require a physicist and an electromechanical technician as a minimum experimental team. Their presence for either long periods of time or for occasional visits will allow changes in instrument positioning, instrument maintenance and repair and major programing changes to be carried out. This will be necessary if the full potential of future experiments is to be achieved, as it is highly likely that fundamental processes not envisaged at present will be discovered.

In the area of actual experimental monitoring and control, it would appear that for the initial experimental periods the physical participation of man is necessary to perform specific tasks. This is especially true in the case of control, docking and refurbishing procedures for the subsatellites. Monitoring of the experiments will enable faults in equipment to be quickly identified with a resultant saving in data transfer, telemetry and evaluation time and a possibility of early rectification of the fault. Furthermore, confirmation of the correct deployment of booms, antennas, etc. can resolve many of the difficulties that arise during the data analysis. On board monitoring of the data, as it is received, will allow, in some cases, early identification of an unusual occurrence together with the possibility of changing the experimental program to study the effect in detail.

The physicist will monitor the data and with the aid of the on board computer will remove useless data and program the delayed time telemetry transmissions. The physicist will only be able to make a cursory appraisal of the data but may be able to judge if a particular experiment has obtained the expected results, observed new effects, or failed and, therefore, make any necessary adjustments to the experimental program.

2.8 SCHEDULE

Refer to Table 2-21 for the schedule of experimental operations.

2.9 SPECIAL PRELAUNCH SUPPORT AND GSE REQUIREMENTS

Normal ground support, GSE, and prelaunch checkout will be required. A special prelaunch requirement will be a portable vacuum system for the checkout of the accelerators, together with a system for monitoring and dumping of the beam. The

Table 2-21. Schedule

Experiment	Experiment Definition (Months)	Engineering Design (Months)	Fabricate Engineering Design (Months)	Test (Months)	Model & Equipment Assembly: Build Flight (Months)	Model & Equipment Assembly: G.S.E. (Months)	Test (Months)	Extra: Train Astronaut in Parallel (Months)
Wake 2.4.1	Six	Six	Six	One	Parallel Effort Six		One	Six
Harmonic Resonance 2.4.2	Six	Three	Four	One	Six		One	Six
Wave-Particle Interaction 2.4.3	Six	Three	Six	One	Six		One	Six
Electron Accelerator 2.4.4	Six	Three	Six	One	Six		One	Six
Remote Subsatellite 2.4.5	Six	Three	Six	One	Six		One	Six

latter is especially important if high beam energies and intense particle fluxes are developed. Furthermore, a radiation shield will be necessary to protect the personnel conducting the tests from any flux of X-rays produced.

2.10 SAFETY ANALYSIS

The types of hazards which will be present will, in general, be the same as in any physics laboratory. Specifically, high voltage and various forms of radiation will be the major dangers.

The wake and harmonic resonance experiments will introduce a high voltage hazard associated with a large portion of the apparatus. In addition, the use of subsatellites will incur a danger from the fuel of the propulsion system and a collision between the laboratory and the subsatellite. The radiation from the VLF and RF transmitters proposed range of operation is not expected to be near a dangerous level, but high voltage hazards will again be present during any EVA activity near antennas. In the case of the particle beams, X-ray radiation, especially from high flux electron sources, will probably require the source to be mounted externally and for adequate radiation shields to be erected. As before, a major hazard will be from the high voltage supply necessary for the accelerator.

2.11 AVAILABLE BACKGROUND DATA

Reference No.	Reference
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3.	J. J. Shea, "Missile-Plasma Interaction Phenomena," Final Report, Contract AF-19 (628)-1964, Cosmic, Inc., 3206 Grace St., N.W., Washington D.C. 20007, 1964.
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6	F. W. Crawford, R. S. Harp and T. D. Mantei, J. Geophys. Res., 72, 1, 57, 1967.
7	R. A. Helliwell, Report of Ad Hoc Committee on Environment Modification Experiments in Space, University of Maryland, 1968.
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9	W. N. Hess, Science, 164, 1519, 1969.
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VOLUME III

SECTION 3

COSMIC-RAY PHYSICS LABORATORY

SECTION 3

COSMIC-RAY PHYSICS LABORATORY

The write-up of this FPE discusses the goals and objectives for a cosmic-ray physics laboratory as one of the complement of experiment modules for a manned space station. Launch and logistics requirements for a "shuttle-only" mode of operation are also discussed.

Five representative experiments were selected and analyzed in terms of experiment and FPE requirements. Individual, as well as total, weight, power, volume, and data rates were derived. In addition, crew skills, logistics, pointing and orbital requirements are defined. A summary data sheet is presented in Section 3.5.

3.1 GOALS AND OBJECTIVES

The study of high-energy cosmic radiation affords a powerful means of probing the universe and aiding in our understanding of various astrophysical phenomena. Measurements of the energy spectrum, nuclear composition, charge spectrum and directionality of the high-energy cosmic rays can yield valuable insights into the age and origin of the universe and of the elements. The cosmic-ray flux carries with it information on the stellar processes that are partly responsible for its origin. The mechanisms that are responsible for supernovae, pulsars, quasars, and matter and magnetic field distributions in the galaxy all contribute to shaping the observed particle fluxes. A study of the primary cosmic-ray flux can, therefore, help in understanding these mechanisms.

Over the past several years, the NASA scientific program has been highly successful in determining the properties of the cosmic radiation below about 10^{10} eV through the use of small satellites, sounding rockets, and high-altitude balloons. The energy region above 10^{10} eV, however, has not been easily accessible to observation for several reasons. Small satellites have not been able to accommodate the large geometrical factors and large instruments required to adequately investigate the relatively low fluxes associated with these high-energy particles. Balloon experiments suffer from limited exposure times and from the ever-present background of secondary particles generated in the remaining atmosphere above the detectors.

The cosmic-ray physics laboratory, as conceived herein, will be an orbiting facility designed to investigate the astrophysical properties of cosmic-ray phenomena at energies greater than 10^{10} eV.

A major design goal has been that of flexibility. Through manned participation and interaction with the facility new experiments can be configured as desired. This will not, in general, involve any changes in the major or permanent items of instrumentation. Thus, a long range program is possible with the flexibility to adapt to those experiments of contemporary interest.

Some of the goals for the cosmic-ray space station facility are listed below:

a. To determine accurately from direct measurement the flux of cosmic-ray nuclei and their charge spectrum from 10^{10} eV to the maximum possible energy. The charge of galactic cosmic rays, their energy spectra and directional properties as well as the time dependence of these features contain astrophysical information about their propagation and features of the containment region. Low-energy cosmic rays have been studied extensively and their characteristics are well known. Measurements of high-energy cosmic rays ($\gtrsim 10^{10}$ eV), however, have been extremely limited and are of much poorer quality. This condition is primarily because of the limitations imposed on weight, size and power by small scientific satellite systems. The high energy range is important. Changes in the shape of the energy spectra or charge composition at high energies would have important astrophysical consequences. Moreover, at high energies the directional properties of these nuclei may start to carry information on the location and other properties of the sources.

b. To determine accurately the electron and positron energy spectrum above 10^{10} eV. It is believed that the energy spectrum of electrons in the primary cosmic rays is related to the origin of cosmic rays in general and to the structure of the galaxy. The observed electron energy spectrum is shaped by the energy dependent losses through synchrotron emission and inverse Compton scattering with photons of starlight and the 3°K black-body radiation. Thus, the shape of the high energy spectrum should provide important clues concerning the age of the electrons, the source spectrum, the acceleration mechanism, the storage times and the distribution of cosmic-ray electrons in the galaxy.

   These experiments can also provide information on the interstellar energy density of photons and the existence of extra-galactic electrons. The electron-positron ratio, as a function of energy, is also important in understanding source and propagation mechanisms. Finally, the time dependence of the electron energy spectrum can be a sensitive measure of solar modulation effects and models.

c. To determine the isotopic composition of the light elements in the primary cosmic rays within certain limited energy ranges. The isotopic composition of the light elements is important in determining cosmic-ray age and production mechanisms as well as providing a measure of the source function and the distribution of interstellar matter. In particular, the abundance of the Be^{10} isotope with a decay lifetime of 4×10^6 years could serve as a measure of the time in which cosmic rays have been confined to our galaxy. Other light isotopes are important in determining source functions and interstellar matter distributions.

d. To search for negatively charged nuclei in the primary cosmic rays. A small number of antiprotons are expected to be created by proton-proton collisions in interstellar space. Their measurement is important and can be interpreted in terms of cosmic-ray lifetimes and the galactic matter density. The creation of more complex antimatter elements, however, through collisions of ordinary matter is negligible. Thus, the observation in the cosmic rays of an antihelium nucleus, for example, would imply the existence of antimatter stars. Such an observation would be of profound astrophysical significance regarding the nature of the galaxy and of the universe.

e. To search for anisotropies in both the nuclear and electron components of high-energy cosmic rays. At energies $\gtrsim 10^{15}$ eV, where the cyclotron radii of the nuclear component becomes comparable to the dimensions of the galactic structure, an anisotropy in this component should be evident if the sources are located in the galactic disc.

   Investigation of the spatial distribution of the electron component of the cosmic-ray flux can lead to important results relating to the magnetic structure in the spiral arm of our galaxy.

f. To investigate, with good statistical accuracy, the flux and charge spectrum of the extremely heavy or very high charge nuclear component of the cosmic rays. Experimentally, some primary cosmic-ray nuclei of charge ~90-100 have been discovered in large area nuclear emulsions. Early measurements of the charge spectrum seem to indicate that these very heavy primaries have passed through less matter than the lighter primaries. These experiments are very sensitive to the presence of the Earth's atmosphere as well as requiring large geometry factors due to the low fluxes. Thus, a space platform experiment is highly desirable. Good experimental data will be important in understanding the synthesis of these elements, the source and acceleration mechanisms, and the nature of their propagation and interaction with the interstellar medium. In addition, the abundance ratios of radioactive transuranic nuclei relative to the long-lived isotopes in this charge range should yield definite information on the age of cosmic-rays and the nature of the source region. There is already theoretical evidence, based on the shell model of nuclei, that an "island of stability" exists in the neighborhood of nuclei of atomic number 114 and mass number 298. No experimental configuration has yet been established. It is, therefore, of interest to seek for such nuclei in the cosmic rays.

g. To search for high-energy, neutrally-charged components of the cosmic radiation. The capability to detect the existence of high-energy photons and neutrons can be incorporated into the facility without major additions to the instrumentation required to achieve the objectives listed above. Precisely because our current understanding of the cosmic radiations leads us to expect that these particles should not be present with observable fluxes, their discovery would be of major importance.

h. To search for theoretically-predicted elementary particles, e.g., quarks and magnetic monopoles, whose elusiveness can be attributed to the nonavailability of sources of artificially accelerated particles of sufficient energy to produce them. The energy spectrum of the cosmic radiation is known to extend beyond 10^{19} eV. Hence, natural sources of energy adequate to produce particles of almost any conceivable properties exist. The discovery of the existence or the establishment of more stringent limits on the existence of such entities would be extremely useful to the progress of our understanding of the fundamental nature of matter.

i. To conduct investigations of the high-energy interactions of elementary particles. This objective would be limited to those experiments which are not feasible with ground-based facilities. Current and projected progress in the development and construction of high-energy particle accelerators has weakened the rationale for conducting high-energy interaction physics studies in the cosmic-ray physics laboratory. Intense and well-controlled beams of protons with energies up to 7×10^{10} eV are now available at Serpukhov (USSR). Protons with energies up to 5×10^{11} eV will be available at the National Accelerator Laboratory (NAL) (USA) within several years. In the same time frame, the Intersecting Storage Rings at CERN (Europe) will yield proton-proton interactions at a center-of-mass energy of 6×10^{10} eV, which is the equivalent of the interactions of cosmic-ray protons of energy 2×10^{12} eV.

The intensity of the cosmic radiation at energies above 10^{12} eV is great enough for a facility such as the cosmic-ray physics laboratory to possibly provide the order of 100 interactions per day. The instrumentation required to perform these experiments would for the most part be the same as that used for the investigations of the properties of the cosmic radiation. The inclusion of liquid hydrogen and deuterium interaction targets would be highly desirable, if not essential.

On the other hand, it is probable that intersecting storage rings will be added to NAL within the next decade. This facility would provide proton-proton interactions equivalent to those of cosmic-ray protons of approximately 10^{14} eV energy. The intensity of the cosmic radiation above this energy is so low that even a facility such as the cosmic-ray physics laboratory will yield less than 100 useful interactions per year.

Limiting ourselves to objectives that cannot be equally well or better accomplished with ground-based facilities, the areas of high-energy interaction physics that can be possibly considered include:

1. Interactions of nuclei with energies $\gtrsim 10^9$ eV/nucleon.

2. Interactions at energies above 5×10^{11} of eV of cosmic-ray protons with neutrons (requires a liquid deuterium target).

3. Interactions at energies above $\sim 5 \times 10^{11}$ eV of photons, and other elementary particles, that can be produced as secondaries in the interaction of cosmic-ray protons with a target.

The above goals are basic for a long range program. As the program evolves and as experimental results become available from this facility as well as other laboratories, the emphasis would be placed on those experiments which reflect the current scientific interest at that time. Moreover, the laboratory would be continually updated by including new instrumentation as it becomes available in order to improve the quality of the data.

The attainment of all these goals is either made possible or greatly enhanced by the presence of man. The specific role of man in this program is discussed throughout the following pages.

3.2 PHYSICAL DESCRIPTION

A typical laboratory layout is shown in Figures 3-1 through 3-5. It has been designed to be housed in a cylindrical module approximately 4.6 meters (15 ft) in diameter and with an inner diameter of approximately 4.1 meters (13.5 ft). The complete module is a two-level structure. One level (experiment deck) contains all the equipment and detectors required for the experimental program. The second level (support deck) contains the bulk of the experiment electronics and control. Figure 3-1 shows a three-dimensional view of the experiment deck. Figures 3-2 through 3-5 indicate in plane sections how the various basic instruments are configured within the module. A functional description of the various components follows.

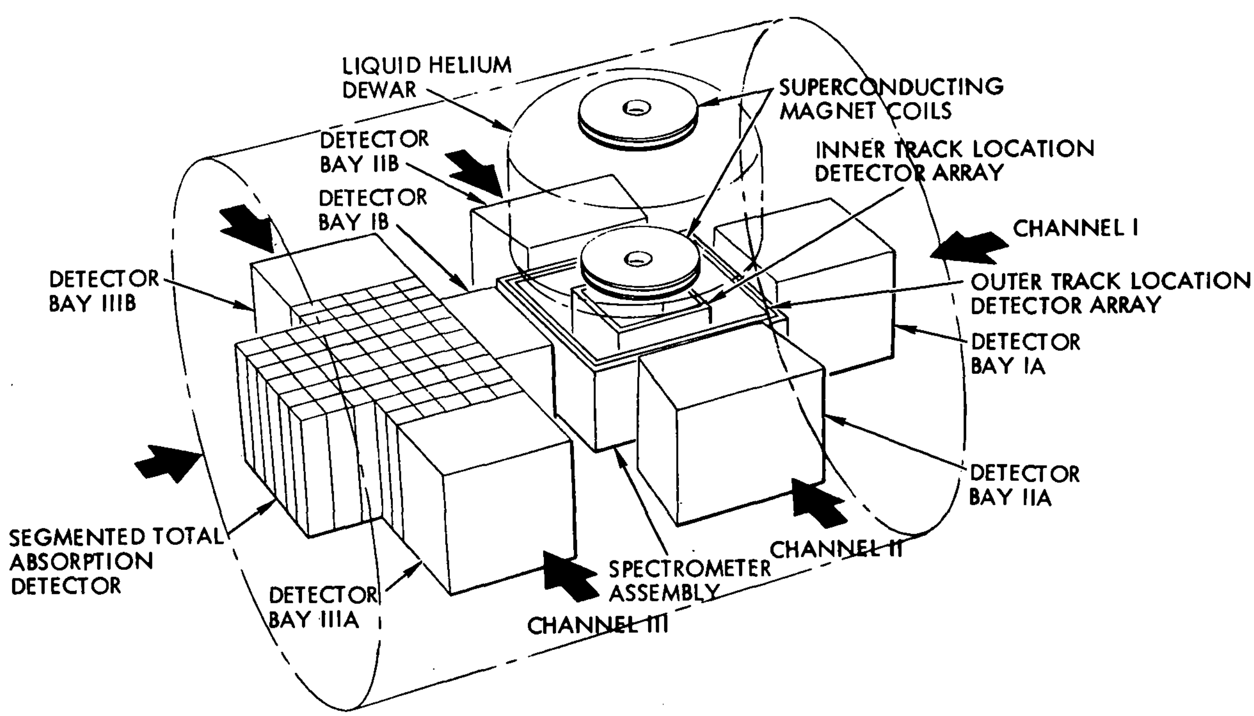


Figure 3-1. Typical Laboratory Experiment Deck

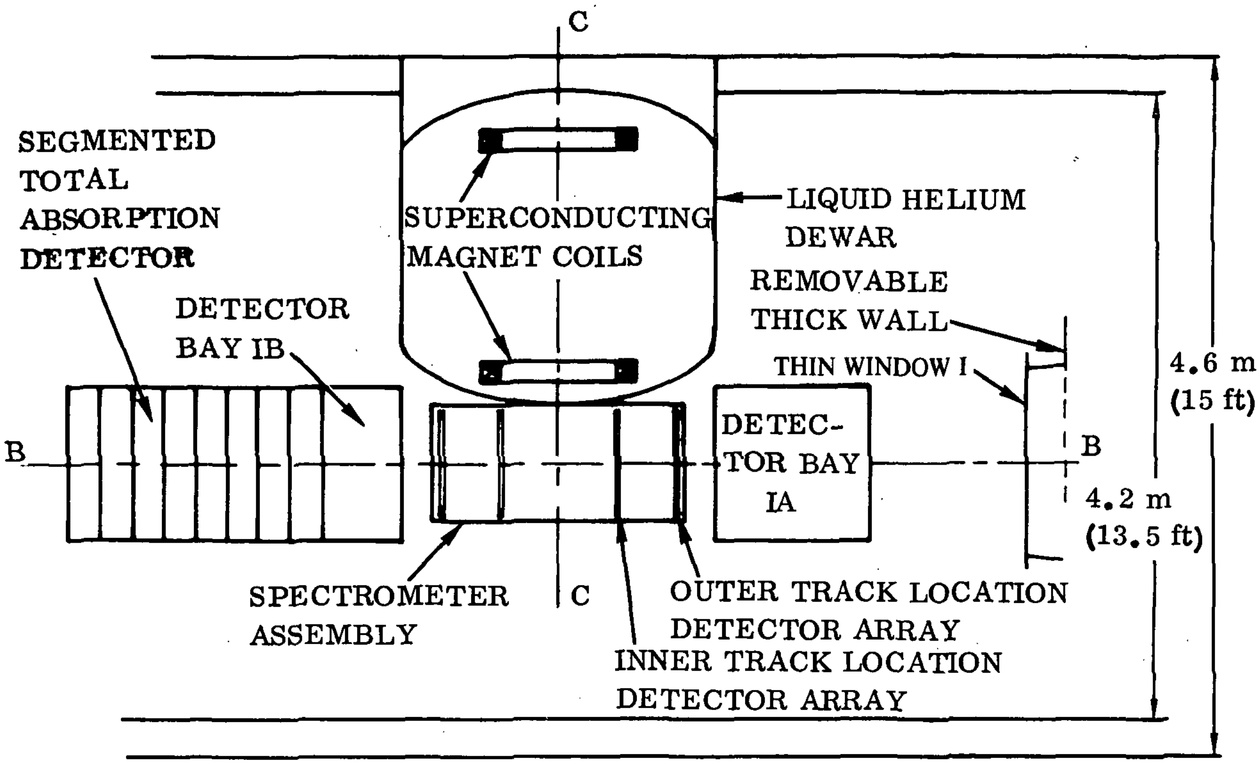


Figure 3-2. Laboratory Experiment Deck Side View

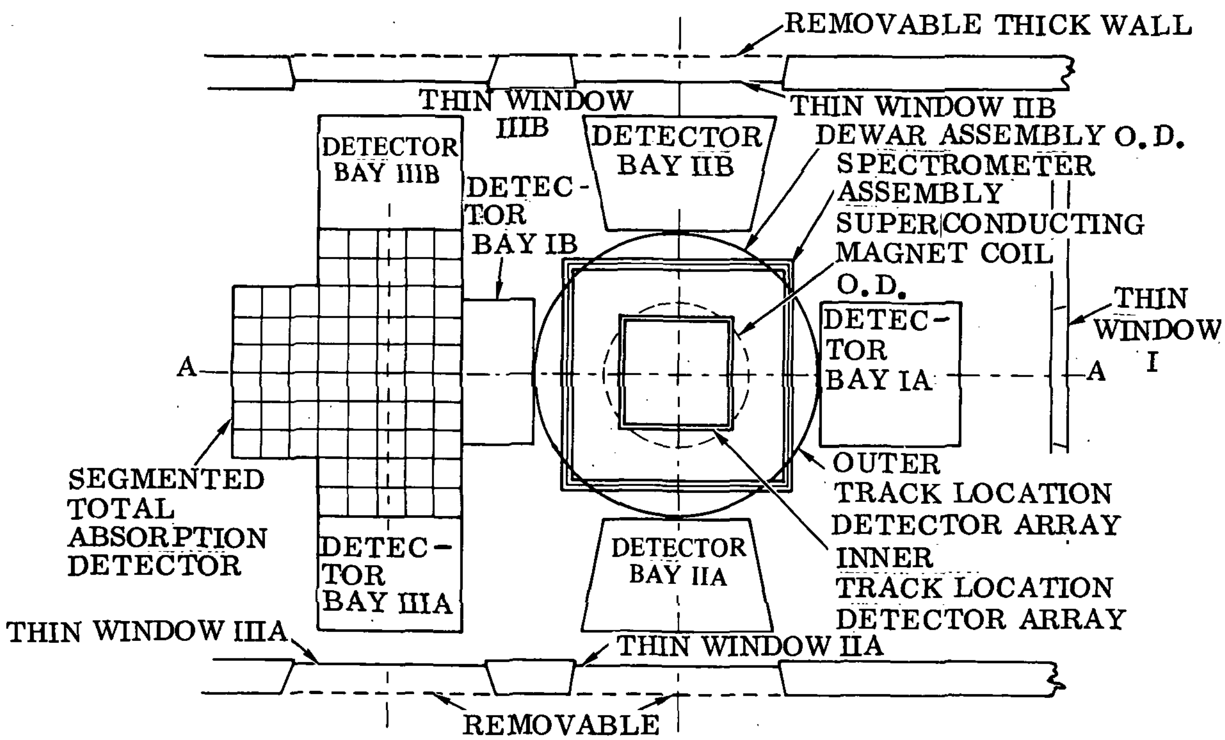


Figure 3-3. Laboratory Experiment Deck Top View

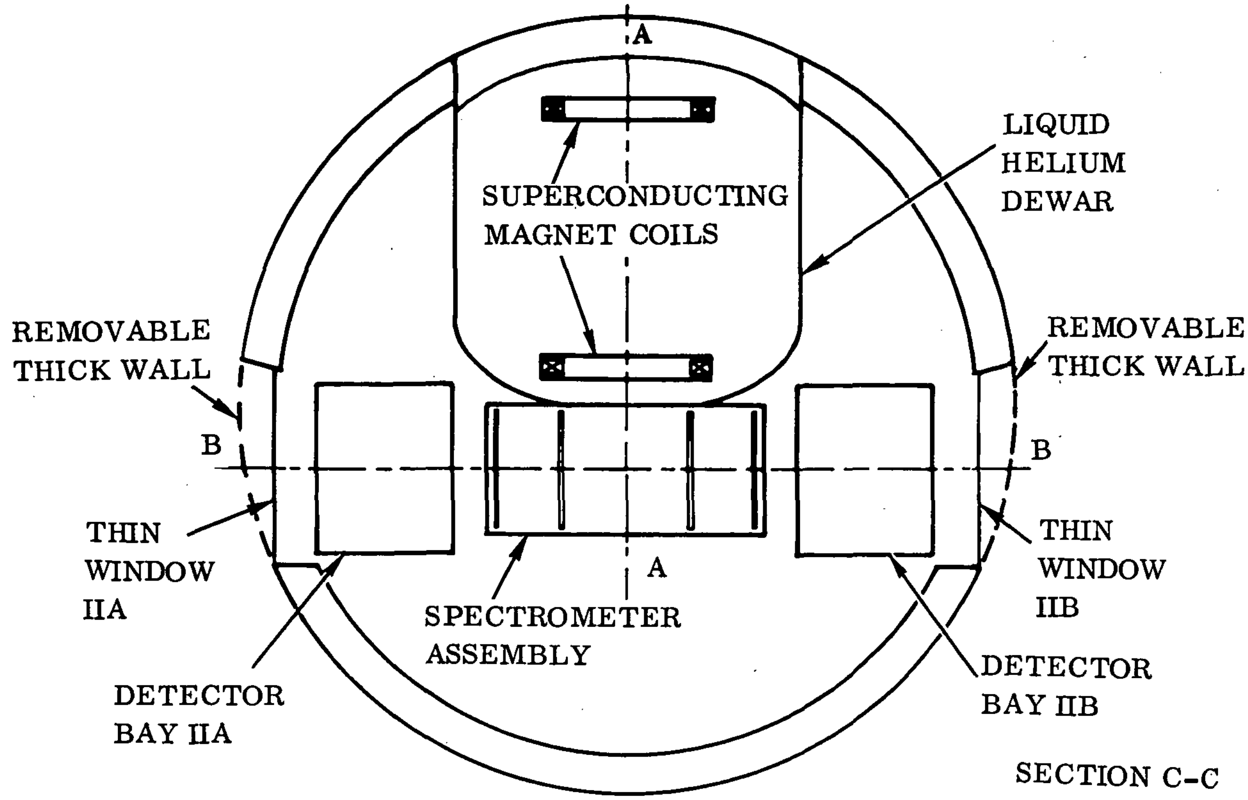


Figure 3-4. Laboratory Experiment Deck Cross-Sectional View

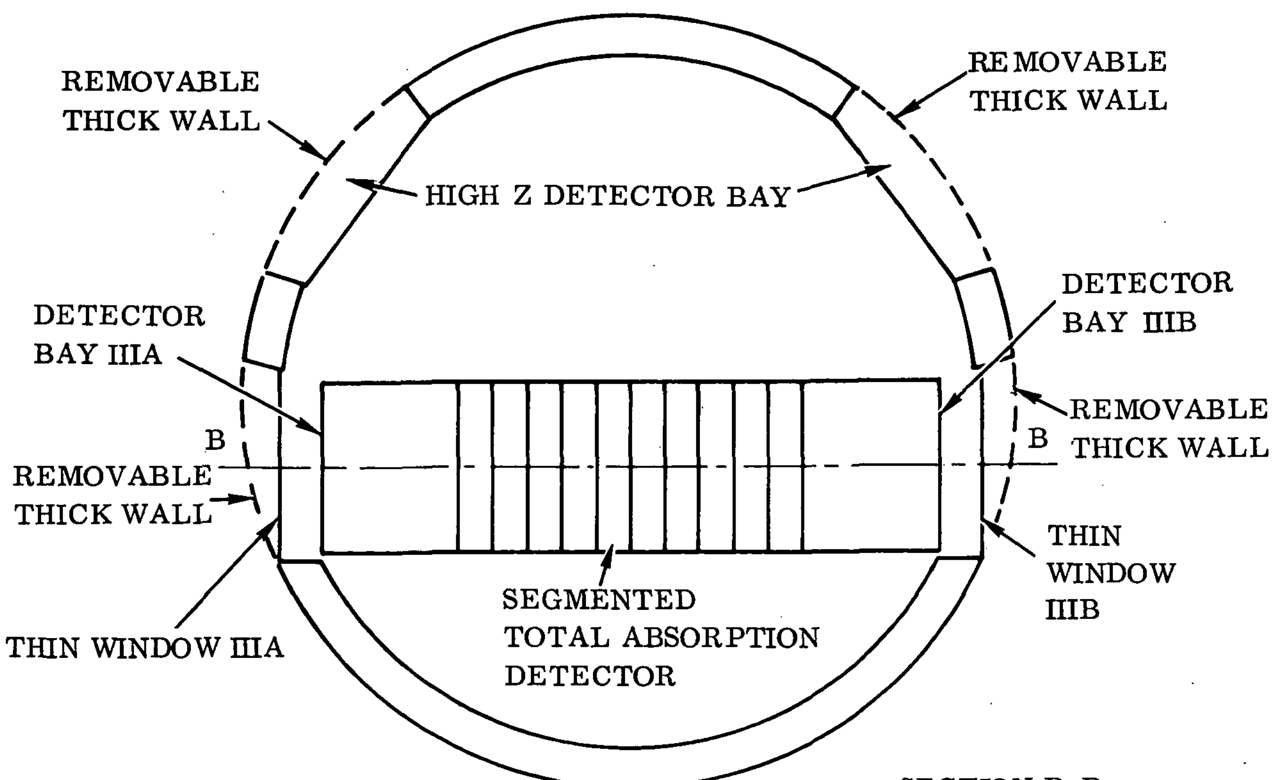


Figure 3-5. Laboratory Experiment Deck Cross-Sectional View

3.2.1 EXPERIMENT DECK. The experiment deck should be 7.6 meters (25 ft) long, to allow sufficient room between it and the support deck for assembly of the total absorption detector, as discussed later in this Section.

The heart of the experiment deck is a tandem, superconducting, magnet-dewar assembly. Only one of the two coils can be used for experiments in the configuration depicted. The second coil is included to reduce the torque experienced in the Earth's magnetic field to negligible proportions.

The two coils are mounted at opposite ends of a cylindrical cryogenic dewar. At the present time, it appears quite feasible to construct a well-insulated dewar of this volume which could contain enough liquid helium to maintain the coils in the superconducting state for about one year without replacement or resupply. From the point of view of safety and cryogenic engineering, replacement of the entire dewar-magnet assembly at one year intervals is preferable to transferring liquid helium into the same dewar at zero g. Thus, access is provided to facilitate removal and replacement of the dewar assembly through a side wall of the module (see Figures 3-2 and 3-4).

The superconducting magnet is a very valuable instrument in terms of providing the detailed information necessary to accomplish the scientific objectives of the facility. A measurement of the radius of curvature of the charged particles as they pass through the magnetic field determines the rigidity (momentum/charge) of the particles up to the experimental limit imposed by the spatial resolution of the entrance and exit detectors. At higher energies, it will still be possible to determine the sign of the charge. This is important in searching for antimatter.

Associated with the magnet is the spectrometer assembly which houses the track location detector arrays. The rigidity resolution limit of the magnetic spectrometer is directly proportional to the spatial resolution afforded by the track location detectors. The baseline design will employ spark chambers with $\pm 10^2$ μm resolution. The capability will exist to incorporate nuclear emulsions with ± 2 μm spatial resolution for limited exposure, high-resolution rigidity measurements. The size magnet envisaged will have an average integral field of about 1.2 tesla-meters (12 kg-meters). With spark chambers as the primary spatial detectors, this implies a rigidity resolution limit of 200 to 500 GV for the spectrometer. The corresponding digital data per event is estimated as 500 bits/event. Advances in superconducting wire technology may increase the resolution by a factor of about 8 by enabling operation at higher critical fields. On the other hand, replacement of the spark chambers by nuclear emulsions will improve the resolution by a factor of about 50. For this experiment, as well as for most of the others, improvements in instrumentation will be incorporated as they become available.

Of comparable value is the inclusion of high resolution total energy absorption devices. These are instruments designed to provide a measure of the total kinetic energy of the incident particle through measurements of the ionization produced by interaction secondaries generated and contained in the device. There are two fundamental requirements for such instruments. First, the total size and thickness must be sufficiently large so that all or most of the energy is dissipated or contained in the volume, and second, a means of detecting and reading out the information must be incorporated. The attainable energy resolution is a function of both of these requirements. One such instrument is the ionization spectrograph or calorimeter. This device is basically a sandwich of layers of high density absorber material and plastic scintillation counters for ionization measurements. Thus, a nuclear cascade shower, developing in the absorber plates, is periodically sampled by the scintillators. A second device, commonly known as a total absorption nuclear cascade (TANC) detector, is the one we have adopted here for the purpose of discussion.

In this device, a dense scintillator, such as cesium iodide, serves as both the absorber and the detector. Other possible materials include heavy glass scintillators or thallium chloride. In the discussions which follow we refer to this instrument simply as a total absorption device (TAD). The size shown in Figures 3-2 through 3-5 represents a total thickness of six nuclear interaction lengths of CsI including the instrument in Detector Bay IB to be discussed in the following paragraphs. The worst case energy resolution for the TANC detector as shown is estimated to be about 15% full width half-maximum (FWHM). The main problem with these detectors at the present time is that interpretation of the data requires that assumptions be made regarding the nature of nuclear interactions at high energies. Calibration of the instrument can certainly be carried out to the limit of energies available at high energy particle accelerators. Beyond this one must extrapolate. Cross-calibration within the limits of the magnetic spectrometer at high energies should simplify interpretation of the TANC data and improve its resolution capabilities. It will be noted from the illustrations that the TAD is of segmented construction. Each segment measures 0.2 × 0.2 × 1 meters (0.66 × 0.66 × 3.3 ft) long and weighs about 159 kg (350 lb). The segmented construction provides the flexibility of deferring part or all of this device for a later logistic supply launch if the module, including the TAD, is weight limited. The facility will still be capable of running many experiments before the TAD is completely assembled in place.

A special case of the TAD is represented by the instrument in Bay IB. It consists of about 0.38 meters (15 inches) of CsI optically decoupled into twenty 0.019 meter (3/4 inch) slabs. This instrument is referred to as a total absorption shower counter (TASC) and is used primarily for total energy measurements of incident electrons. The dominant energy loss mechanism for high energy electrons in matter is via the electromagnetic cascade shower. A 0.019 meter (3/4 inch)-thickness of CsI represents one radiation length for electrons. The TASC is therefore twenty radiation lengths deep and is sampled every radiation length. The energy resolution for 10, 30, and 100 GeV electrons is estimated to be 3, 4, and 5% FWHM, respectively. At 1000 GeV, the estimated resolution is 20% FWHM. With the TAD behind the TASC, the energy resolution should be improved considerably and should approach 1%.

Three channels will be simultaneously available for experiments. A channel is defined by a linear array of instruments and a thin entrance window for acceptance of particles through those instruments.

Channel I is defined by Detector Bays IA and IB and includes the magnetic spectrometer, the TASC, and the TAD. This geometry is shown in Figures 3-1 through 3-3. The total absorption shower counter (TASC) will probably occupy most of Detector Bay IA.

Channel II is defined by Detector Bays IIA and IIB and includes the direction through the magnetic spectrometer orthogonal to that used on Channel I. This channel can accept particles entering from either end. The geometry is depicted in Figures 3-1, 3-3 and 3-4. Detector Bay IIB will house a large deep liquid Cerenkov counter.

Channel III is defined by Detector Bays IIIA and IIIB and includes the direction through the TAD orthogonal to that used on Channel I. This channel is also double ended and can accept particles from either incident direction. The Channel III geometry is shown in Figures 3-1, 3-3 and 3-5. The detector bays will house counters and other instrumentation peculiar to the experiments being run on their respective channels. Normally, these instruments will include plastic scintillation counters, Cerenkov counters, proportional counters, spark chambers, ionization chambers, etc. These are subsequently referred to as "standard" bays with the exception of IB and IIB.

The entrance apertures for each of the experiment channels, except as noted below, are designed to have removable outer walls exposing only thin entrance windows 0.5 gm/cm^2 during experiment operation.

In addition to the above experiment channels, two airlocks are provided in the wall structure of the module for experiments investigating the very high charge nuclear component of the cosmic rays. These are indicated in Figure 3-5 and referred to as the High Z Detector Bays. The advantages of these locations for such experiments is that of zero window thickness while subtending a large solid angle. The outer wall panels are removable while the inner panel provides a pressure interface. The instrumentation in these bays can be either electronic counter detectors or passive plastic and nuclear emulsion packages. The latter technique has been assumed for the remainder of this FPE and experiment description. The number of data bits associated with each instrument and experiment bay as well as the geometry factor for each channel are summarized below.

Instrument	Bits/Event
Magnetic Spectrometer	500
TAD	680
Bay IB (TASC)	200

Instrument	Bits/Event
Bay IIB (Deep Cerenkov Counter)	100
High Z Bay	0
Standard Bays	100 each

Channel	Geometry Factor
I	0.0145 m^2-sr (including TAD and TASC)
I	0.0415 m^2-sr (excluding TAD, including TASC)
II	0.088 m^2-sr (for each direction)
III	0.120 m^2-sr (for each direction)
High Z Bay	3 m^2-sr (for each bay)

3.2.2 SUPPORT DECK. This level, as already mentioned, will contain most of the experiment electronics and control. Only that electronic logic which requires short delay times will be located on the experiment deck. In addition, the following items will also be located on the support deck.

a. A computer and control display for data handling and some experiment control. Hard data storage will be on microfilm.

b. An emulsion storage and processing facility.

c. A photographic (microfilm) storage area.

d. An area for spare detector and electronic board storage.

It is anticipated that the module will carry about 25% spare photomultiplier tubes and about 10% for other detector items. Electronic spares should be 100%. For the shuttle-only mode of operation, this should enable most malfunctioning equipment, if any, to be replaced during the shuttle visit to the experiment module.

A length of about 4.6 meters (15 feet) for the support deck should be completely adequate to house the above items plus any other desirable additions. (See Figure 3-6 in Section 3.5.)

3.3 EXPERIMENT AND FACILITIES REQUIREMENTS SUMMARY

This FPE does not lend itself to a summary breakdown by experiments in terms of size, weight, power, volume, etc. This is because the same equipment is used simultaneously for more than one experiment. Further, some experiments will collect data simultaneously from different sets of instruments. In short, the basic concept is that of a cosmic-ray laboratory or facility.

Three "channels," or acceptance directions, have been defined in which a linear array of instrumentation is configured for various experiments. Each of the three channels has two detector bays associated with it.

The particular instruments within the detector bays are peculiar to the experiments being run on those channels and can be varied to suit a given experiment.

The following charts, therefore, present the desired information in two ways.

The first chart (Table 3-1) indicates how the facility would be utilized for the five representative experiments discussed under Section 3.4. It also shows the experiment time lines, data requirements and environmental requirements. The dashed lines across experiments 1, 3, and 4 indicate alternate or simultaneous modes of running the same experiment on more than one channel.

The second chart (Table 3-2), labeled "Facility Requirements Summary," presents a breakdown of the power, weight, volume, etc., of the functional elements which make up the facility. In addition, the thermal requirements and the data requirements in terms of bits per event are indicated where applicable. All the rows on this chart with the exception of the last two refer to instruments located on the experiment deck. The last two will be located in what is referred to as the support deck or control room area. This configuration is indicated on Figure 3-6 in Section 3.5.

3.4 EXPERIMENT PROGRAM

In the paragraphs which follow, we have selected a representative set of initial experiments. It must be emphasized that the basic instrumentation provided in the module can be adapted to study a variety of other phenomena.

The laboratory concept described herein is only one typical configuration which could accomplish the objectives set forth within the limits imposed by detector resolution and counting statistics. It is important to recognize that state-of-the-art developments in electronics and detector technology will certainly have an impact on the final choice of instrumentation and module design.

The definition of future experiments to fulfill a long range program will depend almost exclusively on the results of previous experiments and contemporary scientific interest. These factors should indicate the interesting areas for further scientific study or for initiating experiments directed toward newly discovered or anticipated phenomena. The five classes of investigations discussed in the following paragraphs represent a possible initial experiment group based on the current goals, as stated in paragraph 3.1.

Table 3-1. Experiment Requirements Summary

Typical Experiments	Facility Utilization: Detector Bays* I	II	III	High Z	Magnetic Spectrom.	TAD	Experiment Time Sched.** Set-Up (hours)	Min. Operating Time (months)	Data Requirements: Rate (kbps)	Hard Return (kg/month)	Unique Environmental Requirements
1. Charge and Energy Spectra of Cosmic-Ray Nuclei	●		 ●		●	● ●	8 8	2 2	15.0 8.0	8.6 microfilm 4.6 microfilm	None
2. Energy Spectra of High Energy Electrons and Positrons	●				●	optional	8	6	0.1	Included in 1.	None
3. Isotopic Composition of Light Elements	 ●	●			● ●	 ●	8 8	6 6	4.0 2.5	2.3 microfilm 1.4 microfilm	Reasonable fraction of orbit at high inclination
4. Search for Nucleonic Anti-matter	●	 ●			● ●		8 8	12 12	Included in 1 Included in 3		None
5. Search for Extremely Heavy Nuclei				●			4 per month	6	0.0	120 emulsions and plastics	Emulsion Shielding Thermal Control
								Total Data	~30 ***	~137	

*All detector bays contain "standard" equipment except for the following: Bay IB - Total absorption shower counter (TASC); Bay IIB - Deep liquid Cerenkov counter for experiment 3.

**Crew skills include as a minimum 1 Nuclear Physicist and 1 Electromechanical Technician.

***This data rate is based on all experiments continuously viewing the celestial sphere. In practice this may be reduced by one-half.

Table 3-2. Facility Requirements Summary

Item		Weight kg (lb)	Volume, m^3	Envelope, meters	Power, watts	Thermal Requirements °K (°C)	Data Requirements, bits per event
Detector Bays (each)							
Quantity	Type						
4	Standard Configuration	45.4 (100)	0.925	1 × 1 × 0.91	10 each	283° to 303° (10° to 30°C)	100
1	IB with TASC	1,360 (3000) 127 (280) (PM)	0.505	1 × 1 × 0.52	40	283° to 303° (10° to 30°C)	200
1	IIB with deep Cerenkov	454 (1000)	0.950	1 × 1.16 × 0.82	10	283° to 303° (10° to 30°C)	100
2	High Z	140 (304)	0.154	1 × 1 × 0.15	N/A	275° to 298° (2° to 25°C) controlled	N/A
Magnet-Dewar Assembly		1,360 (3000)	5.60	2.06 dia × 2.06 long	0*	283° to 303° (10° to 30°C) Minimize Heat Loads	N/A
Spectrometer Assembly		91 (200)	2.04	1.64 × 1.64 × 0.76	10	283° to 303° (10° to 30°C) 293° ± 0.5° w/emulsion (20° ± 0.5°C)	500
Total Absorption Device (TAD)		10,900 (24000) 413 (PM) (906)	2.80	1 × 1 × 2.04 1 × 0.61 × 1.2	140	283° to 303° (10 to 30°C)	680
Control Room		363 (800)	44.0	4.1 dia. × 3.34 long	450	Shirt Sleeve	N/A
Spares and Storage		273 (623)	16.1	4.1 dia. × 1.2 long	N/A	Nominal	N/A
Totals		15,600 (34198) (4,347 (9600) without TAD)	160	4.1 dia. × 12.2 long	690	N/A	N/A

*Magnet requires an additional 160 watts for 24 hours during charging cycle at maximum frequency of once per week.

3.4.1 CHARGE AND ENERGY SPECTRA OF COSMIC RAY NUCLEI

3.4.1.1 Scientific Objectives. The scientific objectives of these experiments have been discussed in Section 3.1 (goals a and e). Briefly, they are to extend the flux measurements of cosmic-ray nuclei to higher energies and to improve our knowledge of their charge composition at high energies.

3.4.1.2 Description. These experiments will run on both Channel I and Channel III. We shall discuss the operation for each of these channels in turn.

3.4.1.2.1 Channel I. Bay IA will contain charge identification and triggering counters. The exact nature of these detectors will depend on the charge group of nuclei being studied and would be varied to suit the particular parameters being sought. The rigidity would be measured by the magnetic spectrometer and the particle would finally be allowed to cascade and dissipate most of its energy in the TAD. Additional triggering counters are associated with Detector Bay IB, the TAD, and the spectrometer assembly.

3.4.1.2.2 Channel III. This channel is double ended for these experiments. Detector Bays IIIA and B will contain instrumentation similar to Bay IA. Again, the total energy is measured by the TAD. No rigidity measurements are made on this channel. However, the geometry factor is more than sixteen times larger so that statistics are accumulated in less time.

3.4.1.3 Observation/Measurement Program. This experiment would be set up as described in the preceding section and would run continuously. A convenient way of estimating the relative duration of the various experiments is by specifying the time required to accumulate a fixed number of events above a given rigidity. If we select 300 GV (150 GeV/nucleon for $Z = \frac{A}{2}$) as an integral point and specify 10^4 events, then the statistics on the experiment will be 1%. If emulsions, rather than spark chambers, are utilized in the spectrometer assembly, then the resolvable rigidity is increased to about 10^4 GV.

The following table shows the event rates on Channel I for various nuclear species with rigidities greater than 300 GV and the time required for 1% statistics. Also shown are the rates for energies greater than 10 GeV/nucleon.

Channel I Event Rates and Exposure Times

Nuclear Species Or Group	Rate (>10 GeV/n) (sec^{-1})	Rate (>300 GV) (sec^{-1})	Time (sec) (For 10^4 events >300 GV)
Protons	4.35	1.9×10^{-2}	5.3×10^{5}
Lithium, Beryllium, Boron	4.35×10^{-3}	5.8×10^{-5}	1.7×10^{8}

Channel I Event Rates and Exposure Times, Contd

Nuclear Species Or Group	Rate (>10 GeV/n) (sec^{-1})	Rate (>300 GV) (sec^{-1})	Time (sec) (For 10^4 events >300 GV)
Carbon, Nitrogen, Oxygen	2.4×10^{-2}	3.2×10^{-4}	3.1×10^{7}
Fluorine	2.2×10^{-4}	2.9×10^{-6}	3.4×10^{9}
Iron Group	1.75×10^{-3}	2.3×10^{-5}	4.3×10^{8}

The above rates have not been corrected for periods of Earth occultation. The average event rates will probably be about one-half of those shown.

The Channel III rates will be a factor of 16.5 larger than those listed above.

3.4.1.4 Interface, Support, and Performance Requirements

3.4.1.4.1 Experiment Channel I, Digital Data Requirements. The number of bits per event for the Channel I instrumentation was specified in Section 3.2.1. The total is 1480 bits/event. The maximum rate at which events would be accepted on this channel is about 10 per second. This rate is limited by the time required to read out and recycle the spark chambers. Dead time generators will be provided to accomplish this limiting. The maximum digital data rate for this experiment running on Channel I is, therefore, about 15 kilobits per second.

Considerable flexibility exists for varying the event rate. Adjustments will be provided for raising either the charge or the energy thresholds thereby decreasing the event rate. This will be done primarily to explore those parts of the charge and energy spectrum where the fluxes are small.

Another possibility for reducing the bit rate is to reduce the number of bits per event in the TAD. This might be accomplished by a computer controlled decision as to which segments of the TAD contain the most information based on a trajectory analysis of the spark chamber read out.

3.4.1.4.2 Experiment Channel III, Digital Data Requirements. This same experiment running on Channel III at a maximum event rate of 10 per second will require about 8 kilobits per second. Otherwise, the same discussion as in Section 3.4.1.4.1 applies.

The following additional experiment requirements are essentially common to the FPE as a whole and are discussed in Section 3.5. These requirements are: power, pointing, stabilization, crew support requirements, ephemeris data, thermal control, orbit altitude and inclination, hard data return, unique environmental requirements, special pre-launch requirements, torque outputs, and magnetic fields.

3.4.1.5 Potential Role of Man. The initial set-up, checkout, and calibration of the experiment will require several astronauts, including at least one physicist-astronaut, for a period of two to three days. Once the experiment is running, it will operate in an automatic mode for as long as desired. If the module is attached to the Space Station, daily monitoring, checkout maintenance, and calibration by an astronaut will be highly desirable. These functions should occupy no more than one to two hours per day. Any malfunctioning equipment would be replaced by the astronaut from the onboard spares as required.

The computer and console on the support deck will provide fast access to all housekeeping information channels and will enable the astronaut to sample and periodically preanalyze the data as a check on proper operation of the experiment.

If the magnetic spectrometer is being used with emulsion plates in the spectrometer assembly, the astronaut will be required to remove and replace the emulsions about once every three days. He would then process the exposed emulsions onboard and store them for later return to Earth.

In the shuttle-only mode of operation there are several options with regard to the use of emulsions. The emulsions could be eliminated altogether. The spatial resolution will then be that afforded by the spark chambers. Alternatively, if the shuttle can stay on station for three or four days with the experiment module, emulsions might be employed during that period. The plates would then be removed, processed and returned to Earth by the shuttle. When the experiment is free flying, the spectrometer assembly would again use spark chambers. This latter alternative probably precludes the opportunity for performing any extensive checkout of the equipment while the shuttle is on station with the experiment module.

Additional material on the role of man at the FPE level may be found in Section 3.7.

3.4.1.6 Available Background Data. The published literature on these kinds of investigations is much too extensive to be included here. Therefore, only a few selected general references are included in the following list:

Reference No.	Reference
1.	Meyer, Peter, "Cosmic Rays in the Galaxy", Annual Review of Astronomy and Astrophysics, Palo Alto, Calif. Vol. 7, 1969.
2.	Hayakawa, S., Cosmic-Ray Physics, Nuclear and Astrophysical Aspects, John Wiley, New York, N. Y., 1969.
3.	Alvarez, L. W., et al, "Superconducting Magnetic Spectrometer Experiment for HEAO", University of California Space Sciences Laboratory Proposal, UCBSSL 374 (1970).

Reference No.	Reference
4.	Proceedings of the International Conferences on Cosmic Rays, sponsored by the Cosmic-Ray Commission of the International Union of Pure and Applied Physics. (These conferences are held every two years. The proceedings of the most recent (11th) held in Budapest, Hungary, are not yet published. The proceedings of the tenth conference appear in the Canadian Journal of Physics, Vol. 46, No. 10, Parts 2, 3, 4, May 1968.)

3.4.2 ELECTRON AND POSITRON ENERGY SPECTRA AND ANISOTROPIES

3.4.2.1 Scientific Objectives. The scientific objectives of these experiments were discussed in Section 3.1 (goals b and e). In general, these are to study in detail the electron and positron energy spectra to energies above 10^{10} eV. The use of a magnetic spectrometer to separate electrons from positrons greatly enhances the value of this experiment. It is believed that the positrons are produced through interactions in interstellar space whereas most of the electrons are produced at the cosmic-ray sources. Different spectral distributions and average path lengths are therefore to be expected.

3.4.2.2 Description. This experiment will run continuously on Channel I with a TASC detector occupying Bay IB. The charge will be identified by the instrumentation in Bay IA and the momentum measured by the magnetic spectrometer. The capabilities of the instrumentation and the energy and momentum resolution for electrons were discussed in Section 3.2.1.

3.4.2.3 Observation/Measurement Program. An important feature of this experimental arrangement is the added ability to separate proton background from positrons by demanding that the momentum in the spectrometer and energy measurements in the TASC agree with each other within the limits of resolution of the respective instruments. In addition, pulse shape discrimination and cascade development in the TASC will be utilized to further separate the background.

In six months' running time one should obtain about 2×10^6 electrons and 2×10^5 positrons with energies greater than 10 GeV. If no spectral steepening occurs, the total number of events above 300 GeV will be about 10^4 and above 1000 GeV will be 2×10^3.

3.4.2.4 Interface, Support, and Performance Requirements - Digital Data Requirements. The total number of bits per event on Channel I excluding the TAD is 800 (see Section 3.2.1). The integral counting rate for electrons and positrons above 10 GeV is 1.4×10^{-1} per second uncorrected for occultation. This leads to a data rate of about 100 bits per second for continuous observation.

Additional support requirements are common to the FPE as a whole and are discussed in Section 3.5.

3.4.2.5 Potential Role of Man. The potential role of man is the same as described in Section 3.4.1.5. Additional material on the role of man at the FPE level may be found in Section 3.7.

3.4.2.6 Available Background Data. In addition to the references cited under Section 3.4.1.6, the following are included for this experiment.

Reference No.	Reference
1.	Daniel, R. R. and S. A. Stephens, Physical Review Letters 17, 935 (1966)
2.	Ramaty, R. and R. E. Lingenfelter, Physical Review Letters 17, 1230 (1966)
3.	O'Connell, R. F., Physical Review Letters 17, 1232 (1966)
4.	Shen, C. S., Physical Review Letters 19, 399 (1967)

3.4.3 ISOTOPIC COMPOSITION OF LIGHT ELEMENTS

3.4.3.1 Scientific Objectives. The scientific objectives of this experiment were discussed in Section 3.1 (goal c). Briefly, the goal is to accurately separate the isotopic components in the flux of cosmic-ray light nuclei up to at least beryllium.

3.4.3.2 Description. This experiment can be run on Channel II, which is the cross channel of the magnetic spectrometer. One of the Bays, IIA or IIB, will include a large liquid Cerenkov counter. The relevant parameter for isotopic separation may be expressed as the ratio of the number of neutrons to the number of protons in the incident nucleus. This parameter may, in turn, be expressed as a function of three measurable quantities. These are: 1) the charge, which can be determined independently by a charge identification counter module; 2) the rigidity, determined by the magnetic spectrometer; and 3) the number of photons produced in the Cerenkov counter.

The experiment would probably accept events from one direction only due to the asymmetry of the instrumentation between Bays IIA and IIB. The estimated geometry factor for Channel II is 0.088 m^2-sr for one direction only.

This experiment is feasible with current techniques only in the relatively low rigidity range. The upper limit of rigidities for which the isotopes are separable depends upon the nuclide and is determined by the resolutions of the rigidity measurement and of the Cerenkov radiation measurement. For example, the resolution of the magnetic spectrometer places an upper limit of about 6 GV for the Be^9-Be^{10} separation. With the selection of a suitable radiator in the liquid Cerenkov detector, it is in principle possible to match the resolution limit of the magnetic spectrometer.

A lower limit on the rigidities at which the experiment can be performed is given by the Earth's geomagnetic cutoff. This is a function of geographic latitude and longitude. Thus, running time for the experiment depends, in part, on what fraction of the orbit is spent in regions of space where the Earth's rigidity cutoff is below about 6 GV. For a 55° inclination orbit, the average minimum rigidity cutoff (which occurs at highest latitudes) is 2 GV, and varies between about 0.25 GV and 5.5 GV depending on longitude. The average fraction of the orbit that is below 6 GV cutoff is about one-sixth.

3.4.3.3 Observation/Measurement Program. This experiment would be set up to run continuously. Events would be accepted whenever the entrance bay is not eclipsed by the Earth and when the cutoff rigidity is less than ~6 GV. The flux of beryllium nuclei between 0.5 and 2 GV is about 10^{-1} m^{-2}-sec^{-1}-sr^{-1}, of which about 80% are stable Be^7 if fully ionized. If we assume that the Be^{10} isotope comprises ~10% of the incident beryllium flux, then the time required on Channel II to collect 10^4 Be^{10} events between 0.5 and 2 GV is about 130 days. Observational inefficiencies due to the local rigidity cut-off would probably increase the time for a 1% experiment to 1 to 2 years. Other light isotopes which lie within the resolution and separation capability of the instruments will simultaneously be accepted and investigated.

The above numbers should not be taken too literally. The fluxes are extrapolations from lower energy data, and the goodness of separation depends on how well the fluctuations and backgrounds can be handled. It is clear, however, that valuable data can be obtained via the long exposure times available above the atmosphere.

Channel I is also available for these experiments at lower energies and with reduced geometry factors.

3.4.3.4 Interface, Support, and Performance Requirements - Digital Data Requirements. The number of bits per event for this experiment running on Channel II is about 600. The flux of Lithium, Beryllium, and Boron between 0.5 and 2 GeV/nucleon is about 0.5 m^{-2}-sec^{-1}-sr^{-1}. Our geometry factor for one direction on this channel is 0.088 m^2-sr. Thus, the expected average bit rate for these nuclei in this energy range is about 26 bits/second. The experiment, however, will probably accept all nuclei from helium through at least oxygen for some fraction of the time. This will increase the rate to about 4 kilobits per second. It may also be possible to run this experiment on Channel I. The TASC may be used as a total energy absorber for nuclei whose energies are less than ~0.5 GeV/nucleon.

The above rates will not be continuous. This is because the geomagnetic cutoff must be low enough to allow these particles to enter which are within the range of resolution of the Cerenkov counter. A computer-controlled program may be possible which would enable this experiment only during those portions of the orbit when the local rigidity cutoff is sufficiently low. In this case there would be a requirement for rough real time ephemeris data.

Additional requirements are common to the FPE as a whole and are discussed in Section 3.5.

3.4.3.5 Potential Role of Man. The potential role of man is the same as described in Section 3.4.1.5. Additional material on the role of man at the FPE level may be found in Section 3.7.

3.4.3.6 Available Background Data. Background data for this experiment appears in the references already cited in Sections 3.4.1.6 and 3.4.2.6. Following is one additional reference:

Buffington, A., "Measurement of Isotopes in Primary Cosmic Rays," NASA Particle Physics Project Memos, 108 and 108A (1969), University of California Lawrence Radiation Laboratory.

3.4.4 SEARCH FOR NUCLEONIC ANTIMATTER

3.4.4.1 Scientific Objectives. The scientific objectives of this experiment were indicated under Section 3.1 (goal d). The basic goal is to search for antinuclei of charge greater than or equal to two in the primary cosmic-ray flux and to establish an upper limit if none are observed.

3.4.4.2 Description. This experiment can run on both Channel I and Channel II simultaneously with other experiments. Any event which through analysis can be identified as an antinucleus will meet the objectives of this experiment. The instrumentation in Bay IA or Bay II will determine the magnitude of the charge. The magnitude spectrometer performs the important function of yielding the algebraic sign of the charge as well as the rigidity if within the resolution capability of the spectrometer. If detected on Channel I, a total energy measurement could be provided by the TASC and TAD. An additional aid in identification might be to look for annihilation products in the TASC. These would be predominantly pions, where the $\pi^\circ \rightarrow \gamma$ decays would initiate an observable cascade shower. This technique is good only as long as the annihilation cross-section is an appreciable fraction of the total interaction cross-section.

To aid in directional discrimination, time-of-flight analysis will be performed between the counters in Detector Bays IA and IB and/or IIA and IIB.

3.4.4.3 Observation Measurement Program. The antiproton flux is estimated to be about 10^{-4} that of the protons if produced by p-p collisions of cosmic-ray protons with interstellar protons. Thus, a continuing search of the data for such events is anticipated throughout the entire operational lifetime of the program.

Taking the predicted antiproton flux, and using the Channel I geometry factor of 0.0415 m^2-sr, one obtains the following results: The time required to observe 10 antiprotons above 300 GV is 2×10^6 seconds. If one adds to this the rate from Channel

II for both directions, then the total observation time is about 3.8×10^5 seconds for 10 antiprotons above 300 GV. In this time, about 2.5×10^4 helium nuclei above 300 GV will have been observed. The expected fluxes of antinuclei with charge $Z \geq 2$ are very small if not absent altogether. If no antihelium nuclei were observed, an upper limit to their flux relative to ordinary helium can be derived. Thus, this experiment will run continuously and allow lower bounds to be placed on the upper limit as a function of time, if none are observed.

3.4.4.4 Interface, Support, and Performance Requirements - Digital Data Requirements. As noted above, the rate of antinuclei events will be completely negligible compared to the other experiments. Additional requirements are common to the FPE as a whole and are discussed in Section 3.5.

3.4.4.5 Potential Role of Man. The potential role of man is the same as described in Section 3.4.1.5. Additional material on the role of man at the FPE level may be found in Section 3.7.

3.4.4.6 Available Background Data.

Reference No.	Reference
1.	Alfvén, H., Worlds-Antiworlds, Antimatter in Cosmology, W. H. Freeman and Company, San Francisco, Calif., 1966.
2.	Alfvén, H., Reviews of Modern Physics, 37, 652 (1965).
3.	Aizu, H., et al, Physical Review 121, 1206 (1961).
4.	Grigorov, N. L., et al, JETP, 18, 272 (1964).
5.	Cline, T. L., Physical Review Letters, 7, 109 (1961).

3.4.5 EXTREMELY HEAVY NUCLEI

3.4.5.1 Scientific Objectives. The scientific objectives have been presented in Section 3.1 (goal f). These objectives are basically to determine the charge composition and energy spectra of the extremely heavy or very high charge (Z) primary nuclei.

3.4.5.2 Description. The baseline design for these experiments involves providing two access ports in the sides of the module as shown on Figure 3-5. Several, one-square-meter sheets of plastic plus nuclear emulsion will be placed in these bays for direct exposure to the high Z flux. Individual primary nuclei will be identified by measuring the ionization produced in both the plastics and the emulsions. This technique affords a means of intercalibration between the two types of detectors. The plastic detectors are orders of magnitude less sensitive to background radiation than are the emulsions. Their response as a function of ionization increases exponentially so that transuranic nuclei differing by only one unit of charge should be distinguishable. This technique requires, however, an absolute calibration of at least one nuclide in the vicinity of Uranium by intercomparison with the emulsion track or from statistical analysis.

The capability exists within the module to investigate the charge and energy spectra of the extremely heavy nuclei by means of counter techniques rather than emulsions. Channels II or III would be most appropriate due to their larger geometry factors. The detector bays could include, for instance, a combination of Cerenkov counters and ionization chambers.

3.4.5.3 Observation/Measurement Program. An important feature of the High Z Bays is that there will be zero window thickness when the emulsion detector packages are in place, and that the solid angle will be nearly π steradians.

An additional feature of these bays is to have a thicker than normal outer sliding wall. Flux monitors in the High Z Bays would then automatically initiate the closing of these ports during passes through the South Atlantic anomaly or whenever the background flux reaches some predetermined level.

Each bay will accept a square meter (10 ft^2) of emulsion, plastic detector, and shielding. The weight of each package breaks down as follows: Nuclear emulsion 30 kg (66 lb), plastic detector 30 kg (66 lb), and copper shielding 10 kg (22 lb) for a total package weight of 70 kg (154 lb).

The emulsions will be stored onboard in shielded and environmentally-controlled containers until used. It is then planned that after use the plates will be developed onboard eliminating the necessity of reshielding. Development of emulsions in a zero G environment appears to be feasible at the present time.

It is anticipated that six months of continuous operation for the two detector bays will yield about 80 relativistic primaries with charge greater than 70.

The detector package described above is based on a shielding thickness which would provide sufficient radiation background protection for a 30-day exposure if the emulsions are underdeveloped. Thus, a 30-day turnover for the detector packages is assumed. If sufficient flexibility with the shuttle is available for different orbits versus payload, then it may be possible to extend the exposure time for emulsions depending on the integrated radiation environment (see Section 3.4.5.4.4).

3.4.5.4 Interface, Support and Performance Requirements

3.4.5.4.1 Digital Data Requirements. No digital data are required for the emulsion experiment. If instrumented as a counter experiment, the data rate will be negligible compared to the other experiments.

3.4.5.4.2 Power. There are no power requirements for the emulsion experiments except for those associated with environmental control of the High Z Bays and the storage areas. These requirements should be negligible compared to the FPE power. The power requirements, if instrumented as a counter experiment, are about 20 watts for Bays IIA and B or Bays IIIA and B.

3.4.5.4.3 Hard Data Return. The exposed and processed emulsions would be returned to Earth at the first opportunity. For a one-square-meter array, one obtains the following weight of hard data return at thirty-day intervals: Nuclear emulsion 30 kg (66 lb) and plastic detector 30 kg (66 lb) for a total of 60 kg (132 lb) every thirty days. These numbers must be multiplied by two to include both of the High Z Bays.

3.4.5.4.4 Unique Environmental Requirements. The background radiation encountered in a 55° inclination, 270 nautical mile orbit severely limits the useful exposure time for the nuclear emulsions. Unshielded nuclear emulsions, sensitive to minimum ionizing, charge one, particles, will become fogged in about three days in the proposed space station orbit.

Most of this background is accumulated during passes through the high flux of trapped particles in the South Atlantic anomaly. It is possible, however, for this experiment to use less sensitive or underdeveloped Ilford G-5 emulsion, for instance. Since the very high Z particles are heavily ionizing, high emulsion sensitivity is not required. The copper shielding used during deployment will stop all protons of energy less than 30 MeV and should not degrade the experiment. These requirements, plus the programmed closing of the outer walls referred to in Section 3.4.5.3, should enable the emulsion-detector packages to remain deployed for 30 days. With a 30-day shuttle turn around schedule, no additional shielding is required for storage. If on-board shielded storage is necessary, it may be possible to make use of the TAD itself to provide this shielding.

The acceptable temperature range, in either the stored or operational condition, is between 275°K and 298°K (2°C and 25°C). Temperatures will be monitored at several points in the package and both the storage container and the experiment bays will be provided with active thermal control.

3.4.5.4.5 Orbit Altitude and Inclination. The shielding requirements in Section 3.4.5.4.4 refer to the nominal space station orbit. If the shuttle-only mode offers the flexibility for a lower inclination orbit [$<10°$ and <370 km (<200 n.mi.)], then unshielded emulsions can be used. They could then remain operationally exposed for up to three months. On the other hand, the flux of high Z particles will be less in the lower inclination orbit. Furthermore, such an orbit would seriously degrade the light isotope experiment discussed in Section 3.4.3.

The following additional experiment requirements are essentially common to the FPE as a whole and are discussed in Section 3.5. These are: crew support requirements, pointing, stabilization, ephemeris data, special pre-launch requirements, torque outputs, and magnetic fields.

3.4.5.5 Potential Role of Man. These experiments utilizing emulsions cannot be carried out onboard the module without the active participation of the astronauts. The plastic and nuclear emulsion sheets must be installed in the High Z Bays by the crew. They must then be removed after about one month and processed onboard. They would then be placed in a controlled storage environment while a fresh set is installed in the bays.

As mentioned in the last section, this experiment, insofar as the shuttle-only mode of operation is concerned, requires monthly rendezvous with the module.

If the experiment is done with counter techniques, then the rôle of man will be similar to that indicated in Section 3.4.1.5. The astronaut time line for this experiment will involve four hours/month each time the emulsion stacks are removed, developed, and replaced. Additional material on the role of man at the FPE level may be found in Section 3.7.

3.4.5.6 Available Background Data. Following are some specific references for this experiment which are in addition to those already cited in Section 3.4.1.6:

Reference No.	Reference
1.	Fowler, P. H., Proc. Roy. Soc. A301, 39-45 (1967).
2.	Blanford, G. E., et al, Physical Review Letters, 23, 338 (1969).
3.	Nilsson, S. G., et al, Nuclear Physics A131, 1 (1969).
4.	Price, P. B., et al, Physical Review, Part D, Vol. III (1971).

3.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

3.5.1 CREW SUPPORT REQUIREMENTS. Provision will be made to allow the crew to work in a shirt sleeve environment whenever their presence is required on the experiment deck. This will be primarily for initial setup and checkout of the experiments and equipment. A pressure bulkhead separates the experiment deck from the support deck. After the experiments are setup, all control, monitoring, and other operational functions will take place from the support deck. When operating attached to the Space Station, the support deck would remain pressurized with a life support atmosphere derived from the Station. All other life support systems for the support deck would likewise be derived from the Station. The experiment deck may operate anywhere from a hard vacuum to one atmosphere pressure.

For the shuttle-only mode of operation, crew support need be provided when the shuttle is docked to the experiment module.

3.5.2 DIGITAL DATA REQUIREMENTS. The event rate for this FPE is limited primarily by the read out and cycling time of the spark chambers. Dead-time generators will limit this to 10 events per second. The experiments will all run simultaneously on the various channels. Channel I, including the TAD, has the highest bit per event requirement (1500) as currently envisaged. Thus, for this channel alone the bit rate is 15 kilobits per second. The total for all experiment channels is about 30 kilobits per second (see Table 3-1). This rate is based on continuous celestial viewing by all experiments. In practice it will probably be reduced by one-half. A desirable rate for future growth should be between 30 and 100 kilobits/second.

It is planned to store as much data as possible on microfilm to reduce real time transmission. There is always the requirement, however, that the experimenter needs access to at least a fraction (~10%) of the raw data.

3.5.3 POWER REQUIREMENTS. All experiments run continuously and much of the equipment and electronics has a common interface with more than one experiment. The estimates below are based on one watt per photomultiplier tube including a converter efficiency of 25%.

Experiment Deck

Item	Power (Watts)
TAD	140
TASC	40
Deep Liquid Cerenkov Counter	10
Standard Detector Bays	10 each
Spectrometer Assembly	10
Magnet	0 (160 watts for 24 hours during charge)
TOTAL	240 + 160

Support Deck (Control Room)

Item	Power (Watts)
Computer	150
Microfilm System	100

Support Deck (Control Room), Contd

Item	Power (Watts)
Control Console with Scope	100
Miscellaneous Logic Supplies, Amplifiers, Discriminators, Scalers, etc.	100
TOTAL	450

Based on the preceding estimates, the total raw power for the FPE experiments and control room support is 690 watts continuous plus an additional 160 watts for the magnet power supply. This additional power will be consumed for a period of about 24 hours at a maximum frequency of once per week. After charging there is no power dissipation in the magnet coils.

The photomultiplier tubes will all have to be adequately shielded from stray magnetic fields. If this is done by using electromagnetic shielding rather than simple magnetic shielding, the power requirements will increase while the weight will probably decrease. The experiments are expected to require about 230 photomultipliers.

The power requirements are summarized on Table 3-2 and at the end of this section.

3.5.4 POINTING AND STABILIZATION. There are no fine pointing or stabilization requirements on the FPE experiments. There is, however, a requirement that each channel accept events only when not viewing the Earth or the horizon in order not to degrade the data. This poses some limitations on the efficiency of data collection as a function of time. The present module design will, therefore, probably require some programmed scanning to minimize the time that each channel views the Earth or its horizon. It may also be desirable to provide some automatic control which would disable a given experiment channel when it was not pointed within, say, ±45° from the zenith. The instantaneous attitude and orientation of the experiment module will need to be known for each recorded event. The angular coordinates need be no better than a few degrees.

3.5.5 THERMAL CONTROL. If nuclear emulsions are used in the spectrometer assembly their absolute temperature as well as their temperature gradients must be controlled to within about one degree. The desirable operating range of most of the equipment and electronics is from 283° to 303°K (10° to 30°C). However, thermal stresses, gradients, and cycling should be minimized to prevent damage to the TASC and TAD in particular.

3.5.6 ORBIT ALTITUDE AND INCLINATION. The orbit altitude and inclination are not especially critical. A low inclination orbit would be preferable for the use of emulsions. The light isotope experiment, on the other hand, can only be done well with the proposed techniques if the rigidity cutoff is below about 6 GV. This implies a high inclination orbit.

In general, the orbit should be selected so as to minimize the flux of trapped radiation encountered -- especially the time spent in the South Atlantic anomaly. The preferred orbit, therefore, for most of the experiment is 28° × 370 km (200 n.mi.).

3.5.7 WEIGHT AND VOLUME. The weight estimates of the major items of equipment are summarized in the following table: An unshielded photomultiplier tube with potted base has been estimated to be 0.9 kg (2 lb). Also, 2.3 kg (5.1 lb) of magnetic shielding increases the weight per tube to 3.2 kg (7 lb). It has been assumed that all tubes will be shielded.

If electron sensitive nuclear emulsions are to be used in the magnetic spectrometer they must be shielded by about 0.04 kg/cm^2 equivalent of copper to survive 30 days in a 55° × 500 km (270 n.mi.) orbit. Storage shielding could be provided by the TAD. Additional weight associated with this shielding has not been included in the following tables.

Experiment Deck

	Weight	
Item	kilograms	(pounds)
TAD (total when fully assembled)	10,900	(24,000)
TAD - PM's	413	(910)
TASC	1,360	(3,000)
TASC - PM's	127	(280)
Magnet-Dewar Assembly	1,360	(3,000)
Liquid Cerenkov Counter	454	(1,000)
Spectrometer Assembly	91	(200)
Standard Detector Bays (4)	45 (each)	(100) (each)
High Z Shielded Detector Package (30-day supply)	140	(308)
TOTAL	15,025	(33,098)

Support Deck (Control Room)

Item	Weight kilograms	(pounds)
Control Room		
Control Console	91	(200)
Computer with Microfilm Recorder	227	(500)
Emulsion Processing	45	(100)
Storage and Spares		
Spare Detectors	73	(160)
Spare Electronic Boards	91	(200)
Spare Photomultipliers (unshielded)	55	(120)
Spare Gas	45	(100)
Microfilm Storage	9	(20)
TOTAL	636	(1,400)

The total FPE weight is thus estimated to be 15,660 kg (34,498 lb) exclusive of module structure. As indicated in Section 3.2, the TAD can be all or partly omitted from the initial payload. It would then be assembled in orbit at a later time when supplied by the shuttle. If this instrument is not included initially, then the total weight, exclusive of structure, becomes 4,347 kg (9,588 lb).

The total FPE volume is defined by the envelope as shown in Figure 3-6. It is a cylindrical module approximately 12 meters (40 ft) long by approximately 4.6 meters (15 ft) in diameter. These weight and volume figures are summarized on the Table 3-2 and at the end of this section.

3.5.8 HARD DATA RETURN. There will be two types of data to be returned to Earth. One is the digital data record which will be stored on microfilm. The other is the exposed emulsion packages.

A continuous digital data rate of 25 kilobits/second is equivalent to 2.16×10^9 bits/day. If this were to be stored on magnetic tape it would require about 4.2×10^{-2} m^3 (1.5 ft^3 of storage area per day. It is planned, therefore, to interface an optical laser recorder to the computer and record on microfilm. Some of these devices have the capacity to read in or out at rates up to 10^7 bits per second. A 0.27 m (10-1/2 in.)-reel of 8 mm microfilm can store 4×10^9 bits. Thus at the above data rate, about sixteen 0.27 m (10-1/2 in.) reels of microfilm would be accumulated every 30 days for return

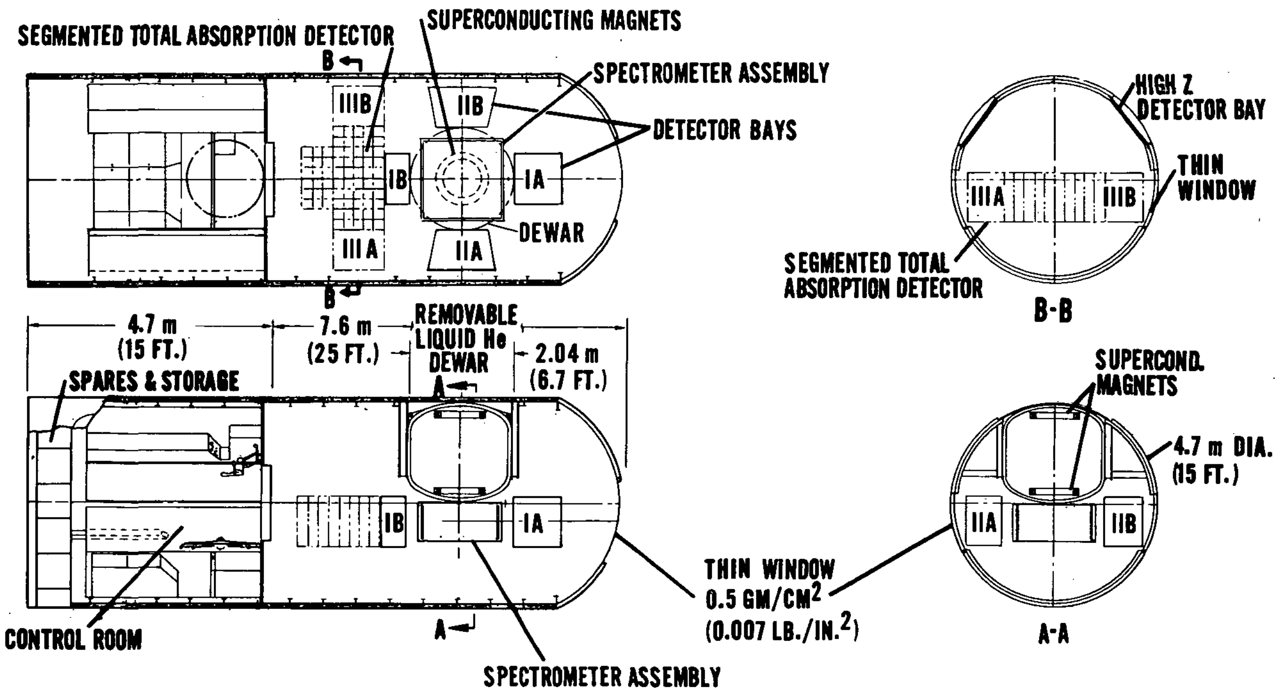


Figure 3-6. Cosmic-Ray Laboratory Module

to Earth. These reels would occupy a volume of 7×10^{-3} m^3 (0.25 ft^3). Assuming a density of 2×10^3 kg/m^3 (122 lb/ft^3) one obtains a weight of 14.5 kg/month (32 lb/month) of microfilm.

The weight of emulsion-plastic sheets to be returned to Earth every 30 days was derived in Section 3.4.5.4.3. This weight was estimated to be 120 kg (264 lb).

3.5.9 TORQUE OUTPUTS. The tandem magnet design virtually eliminates the interaction between the superconducting magnet and the Earth's magnetic field. If the two magnets are properly matched and the currents are equal and opposite, then the only interaction is through the local gradient of the Earth's field. The torque in this case is estimated to be the order of 10^{-6} m-kg (10^{-5} ft-lb).

3.5.10 MAGNETIC FIELDS. The magnetic field intensity along the common magnet axis, as measured in either direction from the center of the dewar, is estimated to be 3×10^{-3} tesla (30 gauss) at 3.8 m (12.5 ft) and 10^{-3} tesla (10 gauss) at 5 m (16.5 ft). In a direction parallel to the module axis and measured from the same point, the 3×10^{-3} tesla contour will be at about 3 meters and the 10^{-3} tesla contour at about 4 meters. Beyond these distances, the field should fall off roughly as the fourth power of the distance.

The instruments most sensitive to fringe magnetic fields will be the photomultiplier tubes and the computer memory. Photomultiplier tube shielding was discussed in Sections 3.5.3 and 3.5.7. The on-board computer will probably use a MOSFET memory rather than magnetic cores. These memories are cheap, effective, and much less sensitive to magnetic fields.

3.5.11 SUMMARY CHART. The FPE Interface and Support Requirements are summarized in the charts on Tables 3-3 and 3-4. A breakdown of some of these items was presented in Section 3.3.

The summary data presented in these charts represents, in the best judgment of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experiment program for this FPE. The rationale for selection of the summary parameters is in some instances arbitrary but it has for a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

The weight, volume, power, and logistics requirements should be increased by about 10% in order to provide a capability for growth.

A conceptual drawing of how the complete cosmic-ray laboratory module might look is presented in Figure 3-6.

3.6 POTENTIAL MODE OF OPERATION

There are three modes to be distinguished under this heading: A) limited on orbit stay time with the shuttle, B) extended on orbit stay-time revisited periodically by a shuttle, and C) extended on orbit stay-time attached to the Space Station.

Mode A will not be considered here since all the experiments of interest require an extended on-orbit stay time. Modes B and C are discussed below.

3.6.1 MODE B. The advantage of a free flying module which is revisited at about 30-day intervals by a Shuttle is primarily one of potential orbital flexibility. This flexibility may be interpreted in terms of achieving orbits which may be better suited to the particular experiments and/or providing a greater payload capacity than could otherwise be achieved in a 500 km (270 n. mi.) × 55° orbit.

Another important advantage for this mode of operation is that the laboratory could presumably be launched and experiments could commence at an earlier time than would be possible if an operational Space Station were required.

The disadvantages to this mode are the additional complexity in terms of control, command, power, communications, propulsion, etc. which would have to be added on if the experiment module were not attached to a Space Station. An additional disadvantage is the absence of man on a daily basis for monitoring, adjusting, maintenance, calibration, etc.

Table 3-3. FPE Interface and Support Requirements

Item	Requirements		
	Task	Time	Skill
Crew Support	Setup and Maintenance	40 hours/month 40 hours/month	Physicist (7) Technician (12)
	Monitoring and Control	2 hours/day	Physicist (7)
Digital Data	30 kilobits/second ($\geq$10% real time sample)		
Power	690 watts continuous; +160 watts for one day at max frequency of once per week		
Pointing, Stabilization, Ephemeris Data	No pointing, no stabilization. Ephemeris data to determine orientation in inertial coordinates to approximately ± one degree accuracy, and real time geographic latitude and longitude to ± one degree accuracy Orientation such that experiment channel look directions scan celestial sphere and spend minimum time pointing at Earth		
Thermal Control	Spectrometer Assembly with emulsions 293° ± 0.5°K (20 ± 0.5°C). General 283° to 303°K (10° to 30°C)		
Orbit	500 km (270 n.mi.) × 55° acceptable; 370 km (200 n.mi.) × 28° preferred		
Weight	Maximum: 15,660 kg without module structure; Minimum: 4,347 kg without module structure and without TAD		
Volume	160 m^3 - based on cylindrical module of 4.1 m inner diameter by 12.2 m long		
Hard Data Return	17 kg microfilm per month; 120 kg emulsions and plastic detector per month		
Torque	10^{-6} m-kg		
Magnetic Fields	FPE associated equipment is solvable problem; Less than Earth's field at Space Station		
Mode of Operation	All the above for attached to Space Station; For shuttle-only mode need to add power, life support, etc. as required		

Table 3-4. Summary Data Sheet

Weight (kg)	Max. 15660 without module structure Min. 4347 without module structure and without TAD
Volume (m^3)	160 derived from cylindrical module 4.1 m inside diameter × 12.2 m long
Power (watts)	690 continuous +160 with max. duty cycle of 14%
Crew Skills	Nuclear Physicist #7, Electromechanical Technician #12
Data Rate	30 kilobits per second (can be decreased if necessary)
Logistics Up	157 kg per month plus 1360 kg ~ once per year
Logistics Down	157 kg per month plus 950 kg ~ once per year
Pointing and Stabilization	No pointing requirements other than that experiment channel look directions scan celestial sphere with minimum pointing at Earth. Inertial coordinates to ±1°
Orbital Altitude and Inclination	500 km (270 n.mi.) × 55° acceptable 370 km (200 n.mi.) × 28° preferred
Unique Environmental Requirements	None, other than to minimize time spent in South Atlantic anomaly

3.6.2 MODE C. The advantages of being attached to the Space Station are basically those associated with a permanent manned orbiting laboratory. Most subsystem and life support requirements are assumed to be provided by the Station. Greater reliability and flexibility in the experiment operation and performance is achieved by the continuous presence and availability of man.

This mode of operation also provides the potential for incorporating new instrumentation and technology as such items become available. Thus, a long term program including new experiment configurations is possible. There are no particular disadvantages associated with the Space Station mode of operation other than the inherent time delay in launching this FPE if there were to be no Shuttle.

Reference has already been made to orientation requirements in Section 3.5.4. The orientation of the module with respect to the Earth, for either mode of operation, should be such that the entrance apertures for the three experiment channels (five directions) as well as the High Z Bays are not eclipsed by the Earth or its horizon. In other words, each entrance direction should receive full sky coverage on the average without Earth obscuration.

The philosophy adopted herein for a manned cosmic-ray physics program is one in which this module would be launched at the earliest opportunity compatible with Shuttle availability and experiment module development. At a later time when a Space Station became operationally available, the cosmic-ray laboratory would preferably become a permanent module attached to the Station.

3.7 ROLE OF MAN

In addition to those already mentioned, the following astronaut tasks apply to the FPE as a whole.

The man primarily responsible for the operation of the laboratory should be a physicist and thoroughly familiar with all the experiments and associated instrumentation. A less highly trained man will be useful during deployment and for routine monitoring of the experiments. After deployment and checkout has been completed, the primary function of the man will be to monitor the performance of the experiments and to troubleshoot and carry out maintenance when needed.

The astronaut will also be responsible, with the help of the computer, for data management including pre-analysis and preprocessing as required prior to transmission. Malfunctioning electronic modules or detectors which could not be repaired on board could be returned to Earth, if feasible, and new equipment resupplied from Earth to spare storage.

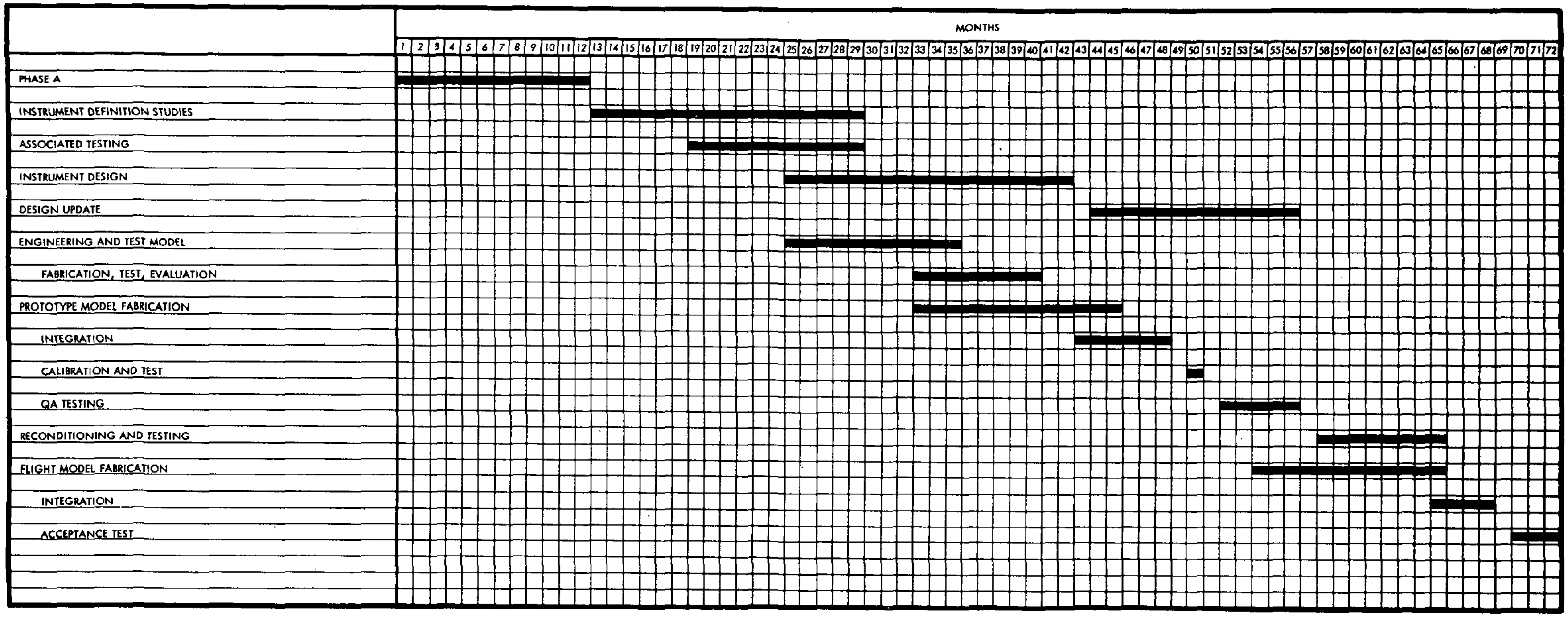
The periodic replacement of the magnet-dewar assembly, as currently envisioned, is without question a manned operation. Even if a cryogenic refrigerator is included at a later time as a growth item, manned attendance is anticipated for maintenance and monitoring of proper operation. The spark chambers, and possibly other gas detectors, will require periodic refilling or resupply of the appropriate gases. Man will be required to perform these operations.

The presence of man is certainly necessary when reconfiguring different detectors for different experiments as well as for performing the important task of deployment, replacement, and processing of nuclear emulsions.

3.8 SCHEDULES

It is estimated that about six years will be needed from the beginning of Phase A to flight. The accompanying milestone schedule (Table 3-5) represents the best estimate for all the instrument development required for the cosmic-ray physics laboratory.

Table 3-5. Cosmic-ray Laboratory Instrument Development Schedule



3.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

The only unusual prelaunch support requirements are those associated with filling and control of the liquid helium system. This requirement will involve precooling from a liquid nitrogen storage dewar included in the GSE. Following this operation, the system would be flushed with gaseous helium to remove any residual nitrogen. The system would then be evacuated and filled with liquid helium from a dewar which is also part of the GSE. After thermal gradients have been established, the flight dewar would be topped off with additional liquid helium and all GSE cryogenic systems would be secured.

3.10 SAFETY ANALYSIS

The following potential hazards should be recognized:

a. The presence of high voltage (~ 5 kV for spark chambers and ~ 2 kV for photomultipliers). This hazard can be minimized or eliminated by adhering to standard practices regarding high voltage safety and by careful engineering design.

b. Possible instabilities associated with the superconducting magnet due to the large potential energy stored in the magnetic field. This potential hazard can be minimized by careful engineering design, thorough testing of the magnet, and operating at a maximum field strength sufficiently removed from critical instability. The multistrand wire, now being used for superconducting magnet coils, should be free from flux jump instability. A program is currently underway to have a superconducting magnet man-rated for space flight.

c. The stray magnetic field may present a problem for personnel working with ferromagnetic objects, such as tools. Experience has shown, however, that one very rapidly becomes acclimated and adjusted to working in such an environment. In any case, this problem can be minimized by working only with nonmagnetic tools when near the activated magnet.

d. Gases for the spark chambers and other instruments which are stored aboard the module in high pressure containers constitute a potential hazard. This hazard could be minimized by providing a larger volume for gas storage at reduced pressure or more frequent resupply missions. We estimate the gas consumption rate, if a closed system is not used, to be about 0.7 m^3/day (25 ft^3/day).

3.11 AVAILABLE BACKGROUND DATA

Published references have been cited following each experiment write-up. In addition, much of the material upon which this write-up was based evolved from a working group meeting held under the auspices of the Cosmic-Ray Physics Branch at NASA/ Manned Spacecraft Center, Houston, Texas, on August 5-7, 1970. Those in attendance were:

Dr. Richard Kurz
Dr. Robert Golden
Cosmic Ray Physics Branch
NASA/Manned Spacecraft Center

Dr. Zack Osborne
Dr. Rudy Staubert
Dr. Philip Krider
Dr. Charles Orth
NAS-NRC Associates
Cosmic Ray Physics Branch
NASA/Manned Spacecraft Center

Dr. Robert Doolittle
Space Sciences Laboratory
TRW Systems

Dr. Andrew Buffington
Space Sciences Laboratory
University of California (Berkeley)

Dr. Barrie Hughes
High Energy Physics Laboratory
Stanford University

Dr. Ricardo Gomez
Lauritsen Laboratory
California Institute of Technology

Mr. Richard Potter
NASA/Marshall Space Flight Center

Mr. Allan Sures
NASA Headquarters, Code SG

Dr. Robert Madey
Space Advanced Systems
Grumman Aerospace Corporation

Dr. John Dooher
Dr. Eric Pickup
Research Department
Grumman Aerospace Corporation

VOLUME III

SECTION 4

PHYSICS AND CHEMISTRY

LABORATORY

SECTION 4

PHYSICS AND CHEMISTRY LABORATORY

4.1 SCIENTIFIC OBJECTIVES

A laboratory facility will be provided in space to support a wide range of original physics and chemistry experiments, making optimum use of the environmental conditions available. These unique environmental conditions include near-zero gravity, space vacuum, solar radiation, and hypervelocity atomic, molecular, and ion beams.

Because of the near-zero gravity, fundamental fluid and gas thermodynamics studies are possible in a medium which is convection free. New data on the effects of surface tension in liquid are also possible. A study of the effects of gravity in chemical reactions, gas transport, fluid separation, flame chemistry, critical point phenomena, and thermal quantum effects may be made.

The laboratory will provide access to the external environment for performing experiments under high vacuum conditions with a moderate magnetic field and no wall effects. Experiments which have heretofore been volume limited in ground laboratory tests now will have access to a "chamber" whose usable volume spans hundreds of kilometers.

Solar electromagnetic radiation provides a natural ionizing and excitation source for studying chemical phenomena. The incident radiation in earth orbit will amount to approximately 1400 W/m^2 with a radiant energy distribution approximating that from a 5800° K black body. About 52 percent of this radiation lies in the infrared (above 7000 Å) and one and a half percent in the ultraviolet (below 3000 Å). The small amount of radiation available for ionization is still sufficient to ionize a significant portion of the Earth's upper atmosphere, and should provide a usable source of ionization for many chemical experiments.

The laboratory will also provide the opportunity to study gas-surface interactions which are not achievable in ground laboratory facilities. The intense hypervelocity atomic, molecular, and ion beam generated by a spacecraft moving at orbital velocity through the upper atmosphere makes possible the study of particle and gas-surface interactions in the free molecular flow regime.

The resources of the Physics and Chemistry Laboratory will be available to the scientific community to conduct original experiments and obtain original data, with a minimum of expense and lead time required. It is envisioned that the facility will be available to universities and research laboratories, internationally, to pursue many avenues of research. This concept will thus provide new opportunities to experimenters who would otherwise be unable to participate in space experiments.

4.2 PHYSICAL DESCRIPTION

The physics and chemistry laboratory will provide the working areas and equipment to perform and analyze a wide variety of physics and chemistry experiments.

The laboratory will have work stations which receive experiments packaged in standardized configurations as carry-on "suitcase" payloads for plug-in to the work stations. The laboratory will contain the necessary power, gases, vacuum lines, and airlocks, as well as multipurpose test equipment and instrumentation. A central experiment control and data collection system will also be provided.

Table 4-1 lists typical basic laboratory equipment and support equipment of the type which will be included in the laboratory.

Basic laboratory equipment is fundamental to the laboratory and has a major impact on the design of the laboratory structure and subsystems, e.g., some items require hull penetrations, clear working areas, high power and cooling.

Support equipment is general purpose equipment which is relatively small, has low mass, and has limited resource demands. Some of this equipment might be installed and removed for specific experiment needs, depending upon the resources available to this FPE from the spacecraft.

One of the primary requirements of this laboratory is for airlocks to provide ready access to the external environment, and it is necessary that several viewing ports be provided near the airlocks to give several points from which the external phenomena may be observed. It will also be necessary to provide deployment devices and manipulators with which equipment or chemical samples can be handled and operated upon outside the spacecraft. At least two airlocks should be provided, diametrically opposed with respect to the spacecraft axes, so that experiments which require simultaneous operation of dispersing, measuring, observing, or positioning equipment may be accommodated. The airlocks for this laboratory should be of the order of one meter in diameter to relieve the experimenters of the burden of unduly miniaturizing the experiment apparatus which is to be externally deployed.

4.3 EXPERIMENT REQUIREMENTS SUMMARY

The candidate experiments which are described in Section 4.4 were analyzed to determine the resources required from the laboratory and spacecraft by each of the experiments. These requirements are summarized in Table 4-2.

Table 4-1. Physics and Chemistry Laboratory Equipment

Molecular Beam Scattering	Gas/Surface Interaction	Flame Chemistry & Reaction Kinetics	Chemical Laser	Quantum Effects	Gas Reactions In Space	Heat Transfer	Critical Point Phenomena	Typical Experiments / Laboratory Equipment	
•	•		•		•			Airlocks (2): 1 m (3 ft) Dia.	Basic Lab Equipment
•	•		•		•			Feedthroughs: Elect., Fluid, Mech.	Basic Lab Equipment
•	•		•		•			Viewports: Visible, IR, UV	Basic Lab Equipment
•	•	•	•	•	•	•	•	Bench Area, Exp. Setup: 3 m^3 (106 ft^3)	Basic Lab Equipment
		•		•		•	•	Bench Area, g Isolation (10^{-4} g)	Basic Lab Equipment
		•		•				Vacuum Lines	Basic Lab Equipment
		•		•				Fire & Emerg. System	Basic Lab Equipment
		•	•			•		Waste Disposal System	Basic Lab Equipment
		•						Environmental Chamber	Basic Lab Equipment
						•		High Vacuum Chamber	Basic Lab Equipment
				•				Superconducting Magnet	Basic Lab Equipment
•	•						•	Glove Boxes: Vacuum, Clean, Hazardous	Basic Lab Equipment
				•				Cryogenic Supplies: N_2 & He	Basic Lab Equipment
•	•		•		•			Extendable Boom: 12m (40 ft)	Support Equipment
•	•	•	•	•	•	•	•	Data Acquisition System	Support Equipment
		•		•	•	•	•	Cameras: Cine, Still, TV	Support Equipment
•		•	•			•		Gas Supplies	Support Equipment
•	•	•	•		•			Mass Spectrometer	Support Equipment
		•	•		•			Spectrophotometer	Support Equipment
				•				Magnetic Field Meter	Support Equipment
			•	•	•			Electric Field Meter	Support Equipment
•	•	•	•	•	•	•	•	Data Displays	Support Equipment
•	•							Oscilloscope	Support Equipment
•	•		•	•	•	•		Voltmeters, Ammeters, Etc.	Support Equipment
•	•							Frequency Meter	Support Equipment
		•	•			•		Reference Junction	Support Equipment
			•					Optical Calorimeter	Support Equipment
		•						Optical Pyrometer	Support Equipment
		•						Gas Chromatograph	Support Equipment
		•						Emission Spectrometer	Support Equipment
		•	•	•		•	•	Pressure & Vacuum Sensors.	Support Equipment
		•	•	•	•	•	•	Temperature Sensors	Support Equipment
•	•	•	•		•			Displacement & Velocity Sensors	Support Equipment
•	•				•	•		Acceleration Sensors	Support Equipment
•	•		•	•		•		Special-Purpose Power Supplies	Support Equipment
					•			Nuclear Particle Detectors	Support Equipment
					•			Polarimeter	Support Equipment
		•						Electron Spin Resonance Spectrometer	Support Equipment

Table 4-2. Experiment Requirements Summary

Experiment No.	Experiment Title	Crew Skills	Data Rate, bps	Power, kW Avg.	Volume m^3 (ft^3)	Mass kg. (Pounds)	Pointing and Stabilization	Special Environmental Requirements	Safety Requirements	Contamination Outputs	Remote Experiment Location	Experiment Duration (Hours)
4.4.1	Molecular Beam Scattering	Physicist Electromechanical Technician	30 k	0.04	0.098(3.5)	86(190)	Yes, ± 1° into Air Stream	External to Space Station	None	None	Yes	100 (1 hr./dy. for ≈ 3 mo.)
4.4.2	Gas-Surface Interactions	Physicist Electromechanical Technician	45 k	0.03	0.086(3.1)	36(80)	Yes, ± 3° into Air Stream	External to Space Station	None	None	Yes	150 (2 hr./dy. for ≈3 mo.)
4.4.3	Flame Chemistry and Reaction Kinetics at Zero-G	Thermodynamicist Physical Chemist Electromechanical Technician	2 m	0.31	3.5(125)	220(480)	None	10^{-4} g Max.	Fire Danger	Yes	No	500 (4 hr./dy. for ≈6 mo.)
4.4.4	Operational Characteristics of Chemical Lasers	Physicist Physical Chemist Electromechanical Technician	2.4 m	0.07	0.52(18.6)	250(550)	None	10^{-2} g Max.	High intensity laser beam Fire Danger	Yes	Yes, sample coupon	100 (4 hr./dy. for 1.5 mo.)
4.4.5	Quantum Effects at Low Temperature and Zero-G	Physicist Electromechanical Technician	10 k	0.3	1(3.3)	50(110)	None	10^{-4} g Max.	High Pressure	None	No	3 hr/run, 50 runs
4.4.6	Gas Reactions in Space.	Physicist Physical Chemist Electromechanical Technician	1 k	0.20	0.3(10.7)	120(265)	Yes, toward cloud	External to Space Station	None	Yes	Yes	200 (3 hr./dy. for ≈ 3 mo.)
4.4.7	Heat Transfer in a Convectionless Medium	Physicist Thermodynamicist Electromechanical Technician	65 k	2.65	0.14(4.9)	115(257)	None	10^{-4} g Max.	None	None	No	170 (0.5 hr/dy. for ≈ 3 mo.)
4.4.8	Critical Point Phenomena	Physicist Electromechanical Technician	7.2 k	0.25	0.056(2)	60(130)	-	10^{-4} g Max.	High Pressure in Container	None	No	200 (3 hr./dy. for ≈ 3 mo.)

4.4 EXPERIMENT PROGRAM

The candidate experiments described in this section are representative of a wide variety of experimental activities which may be performed in a physics and chemistry laboratory in space. These eight experiments typify the range of support requirements which must be provided by the laboratory facility and its supporting spacecraft.

It is presumed that the results obtained from experiments performed early in the program will give rise to new experiments which have not yet been conceived, but that the new experiments will not impose appreciably greater support demands of the basic laboratory equipment. It should be possible to provide any new support requirements by updating, modifying, or augmenting the laboratory with no major changes to the facility structure or subsystems.

One function of the physics and chemistry laboratory will be to precisely define the environment in which subsequent experiments will be performed, and the expected variations of the individual environmental parameters. These parameters include background vibration in the spacecraft, external atmosphere density and composition, magnetic field intensity and direction, electromagnetic background, and other parameters which affect the experiment processes.

The experiments presented here are used to "size" and define the requirements to be imposed by the physics and chemistry laboratory. They are in no way construed to be the actual experiments to be performed in this laboratory.

4.4.1 MOLECULAR BEAM SCATTERING

4.4.1.1 Objectives. The objective of this experiment is to make use of the hypervelocity atomic, molecular and ion beam generated by the spacecraft moving through the upper atmosphere to conduct particle/particle scattering experiments under free molecular flow conditions. Measurements will be made on the interactions of N_2, O_2, O, He, N_2^+, O_2^+, O^+ and e^-, the principal components of the upper atmosphere at orbiting altitudes, and thermal energy beams of N_2, O_2, He and e^- generated in the experiment. The goal is to measure the scattering cross-sections for these particle/particle interactions to establish tables on the probability of particular interactions leading to chemical reactions, ionization, neutralization, recombination, and the generation of metastables.

4.4.1.2 Description. The experiment shown in Figure 4-1 is to be mounted on a platform positioned away from the spacecraft. The platform mounted experiment is attached to the end of an extendable boom with space access through the scientific airlock. The boom then moves the experiment about 3 meters (10 feet) away from the spacecraft to minimize the effect of the spacecraft's electric field on ions entering the experiment. No special shield is needed to protect the experiment from the spacecraft's outgassing because the outgassing particles are moving at thermal velocities compared to the hypervelocity upper atmospheric particles and are separated out by the mass spectrometer in the experiment. Measurements are made when the experiment is pointed along the spacecraft's velocity vector into the upper atmospheric stream.

The instrumentation shown in Figure 4-1 has a window to space allowing the upper atmospheric stream or beam to enter the experiment. The beam first passes through deflection plates which are used to sweep out ions present in the beam when neutral interactions are being studied. The beam is then chopped by a slotted rotating wheel to produce a 100 Hz modulated beam to improve the signal to noise ratio for detection. The beam proceeds through the scattering chamber where it is scattered by either N_2, O_2, He or e^-. The attenuation of the upper atmospheric beam by scattering is measured by the mass spectrometer consisting of an ionization chamber and electromagnet. By adjusting the magnet field of the mass spectrometer, the various species present in the upper atmosphere are measured.

The electronics include phase sensitive, narrow-band amplifiers which are interfaced with local data presentation equipment in the physics and chemistry laboratory as well as with the central digital data system.

4.4.1.3 Observation/Measurement Program. The basic measurement consists of counting the number of upper atmospheric particles that are scattered by the experiment generated gas particles as these two crossed beams of particles pass through the scattering chamber. The atmospheric beam is first allowed to pass through the chamber with experiment gases turned off to permit counting the total number of atomic and molecular species present per cm^3 in the atmosphere with the mass spectrometer. Using the chopper wheel and phase shifter electronics, the time of flight of the atmospheric particles, and hence their velocity distribution, will be determined.

The on-board gases will be used to conduct a series of scattering experiments. As each experiment beam (N_2, O_2, He, e^-) is turned on, the mass spectrometer will be scanned through mass units 1 to 100 to measure the attenuation caused by these gases scattering N_2, O_2, O, O^+, N_2^+, and e^- out of the upper atmospheric beams. By scanning through mass units 1 to 100 any other atmospheric species (such as H_2 and Ar) present in detectable quantities will also be measured.

4.4.1.4 Interface, Support and Performance Requirements. The primary requirements for these experiments are the airlock, the extendable boom with maneuverable

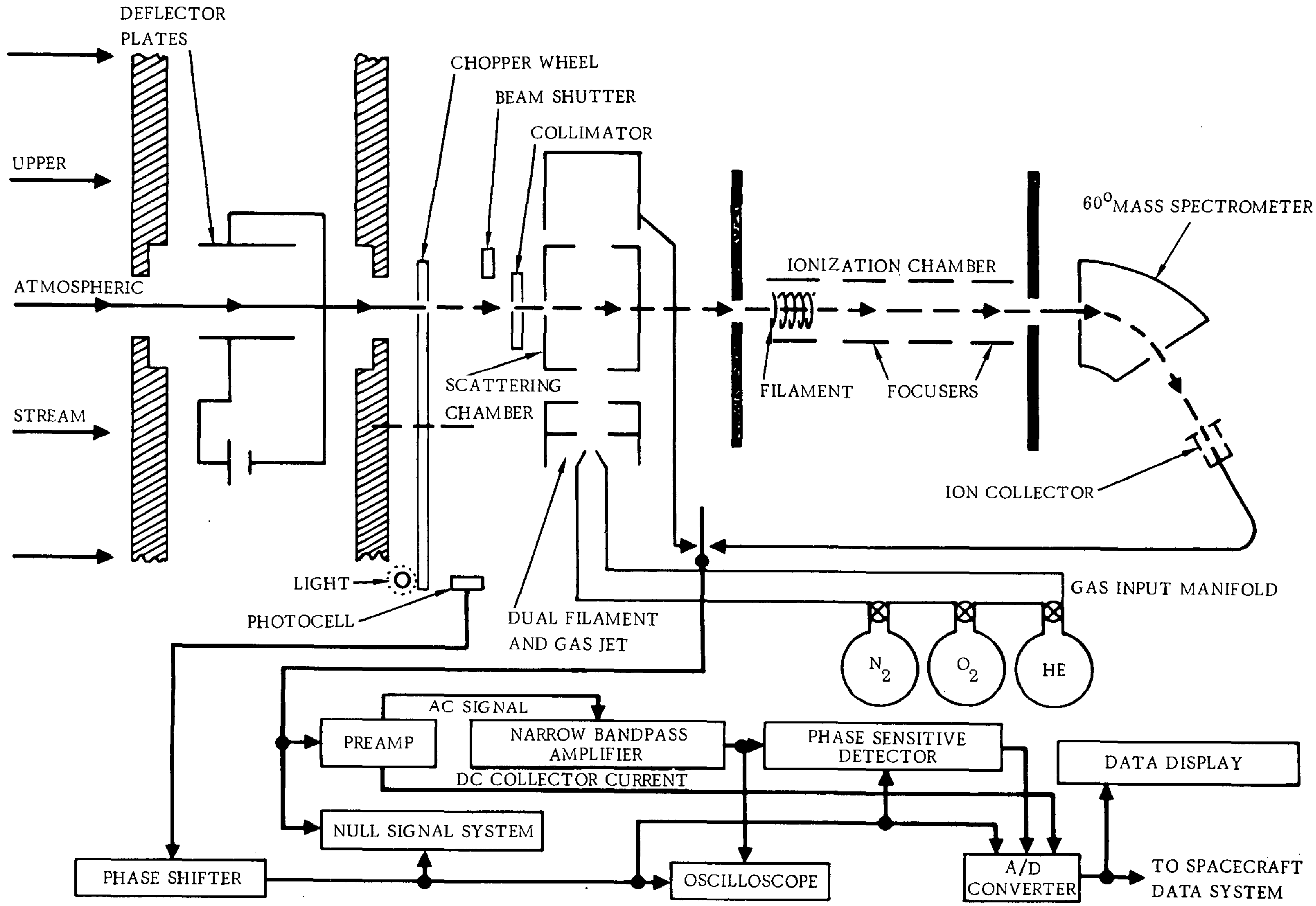


Figure 4-1. Molecular Beam Scattering Experiment

platform and the experiment shielding. These facilities will be provided for use of the entire physics and chemistry laboratory and not necessarily for this experiment alone. The remainder of the equipment items are:

	Mass kg (lb)	Volume m^3 (ft^3)	Power W
Mass Spectrometer	22.5 (50)	0.028 (1)	20
Electronics	18 (20)	0.014 (0.5)	10
Recorders	18 (20)	0.028 (1)	10
Gas Supplies	22.5 (50)	0.028 (1)	--
Resupply (Film, Mag. Tape, etc. 30-day base)	22.5 (50)	0.014 (0.5)	--

The entire experimental program is estimated to last for 80 hours, assuming a two-hour setup and test period for each of five scattering conditions for all eight components (N_2, O_2, O, He, N_2^+, O_2^+, O^+ and e^-) of the upper atmosphere. These five conditions are: no scattering beam; beams of N_2, O_2, He and e^-.

Since the experimental package must be remote from the spacecraft and its window pointed into the local atmospheric flow, either the extendable boom mechanism must point the experiment (assuming the spacecraft is in an inertial hold condition) or the spacecraft attitude must be maintained to provide this pointing for the better part of an orbit for each test condition. Assuming a total of 80 hours operational time, the total energy requirement will be 11.5 MJ (3.2 kW hours).

Assuming a 15 kbit/second data rate requirement for the mass spectrometer and 15 kbit/second for the remaining electronics and test condition transducers, a total data rate of 30 kbits/second is required. The total data requirement for the experiment is 3.3×10^9 bits.

If no continuous pointing arrangement is provided on the extendable boom, then the spacecraft stabilization requirements are assumed to be $\pm 1.7 \times 10^{-2}$ rad ($\pm$ 1 degree) during the active portion of the measurement cycle (about one hour).

There are no other restrictions in this experiment.

4.4.1.5 Potential Role of Man. The astronaut will set up the experiment, operate the experiment equipment making adjustments to acquire optimum data, and will perform preliminary analysis of the data. In concert with the principle investigator he will redefine and reconfigure the next experiment run. He will also be responsible for the maintenance and calibration of the equipment and for the collection, storage and shipping of the data.

4.4.1.6 Available Background Data

a. W. L. Fite, "Some Applications of Modulated Atomic Beam Experimentation," Proceedings of the Atomic and Molecular Beams Conference, Univ. of Denver, Denver, Colorado, 1960, pp. 7-48.

b. R. H. Neynaber, L. L. Morino, E. W. Rothe, and S. M. Trujillo, "Low-Energy Electron Scattering from Atomic Nitrogen," Phy. Rev., 129, March 1963, pp, 2069-2071.

c. R. H. Neynaber, L. L. Morino, E. W. Rothe, and S. M. Trujillo, "Low-Energy Electron Scattering from Atomic Oxygen," Phy. Rev., 123, July 1961, pp. 148-152.

d. C. A. Reber, "Neutral Atmospheric Composition Data from the Quadruple Mass Spectrometer," Proceedings of AGU Annual Meeting, Washington, D.C., April 1970, p. 32.

4.4.2 GAS-SURFACE INTERACTIONS

4.4.2.1 Objectives. The objective of this experiment is to make use of the intense atomic and molecular beam generated by a spacecraft moving at orbital velocity through the upper atmosphere to conduct hypervelocity gas-surface interaction studies in the free molecular flow regime. At orbiting altitudes the principal components of the upper atmosphere are atomic oxygen having an energy of about five eV and molecular nitrogen having an energy of about nine eV relative to the moving spacecraft. The experiment will make use of this beam to measure gas-surface momentum and energy transfer, oxygen recombination and chemisorption at various angles of incidence on engineering and atomically clean surfaces at different surface temperatures. The goal is to establish heat transfer and drag coefficient tables for material used in spacecraft construction.

4.4.2.2 Description. The experiment is shown in Figure 4-2. The experiment is to be mounted on a platform positioned away from the spacecraft. The platform mounted experiment is attached to the end of an extendable boom with space access through the scientific airlock. The boom then moves the experiment about 10 feet out in front of any appendage on the spacecraft pointing it away from materials outgassing from the spacecraft. Measurements are made when the experiment is pointed along the spacecraft's velocity vector into the upper atmospheric stream.

The instrumentation shown in Figure 4-2 has three windows to space allowing the upper atmospheric stream to enter the experiment. The top opening directs the airstream or beam to impact on one of the test surfaces mounted on an hexagonal block. The block is fitted with six different test surfaces. Several blocks would be carried on the spacecraft and changed by astronauts to carry out an experiment series.

The blocks are originally fitted out with engineering surfaces prepared on the ground. Atomic clean surfaces would be evaporatively plated onto the block in situ once the spacecraft has reached orbit and measurements on engineering surfaces were completed. Three plating sources are shown to provide redundancy. The boat holding the plating material, such as Al, Au, or Cu, would be periodically changed by a crewman to provide a measurement series of about twenty different surfaces.

The surface is stepped through nine angles to the airstream between normal and grazing incidence. At each angle the mass spectrometer scans the spatial distribution of the reflected beam of O and N_2, and measures the time of flight of the particles from the chopper wheel until detection by the spectrometer.

The total kinetic energy of the airstream is found by measuring the stream flux with a quartz crystal energy transfer probe.

The condition of the surfaces is measured by the quartz crystal microbalance. Any condensable outgassing from the Space Station reaching the experiment will be absorbed on the microbalance. Periodically, atomically clean surfaces of metals will be plated onto the microbalance to determine how surfaces are affected by the space environment, e.g., chemisorption of oxygen.

4.4.2.3 Observation/Measurement Program. The purpose of the experiment is to measure gas-surface interactions in the upper atmosphere on engineering and automatically clean surfaces at different surface temperatures leading to momentum transfer, energy transfer, surface recombination of atomic oxygen and chemisorption. Surfaces to be studied range from light atomic weight to heavy atomic weight materials, such as, Be, C, Al, Fe, Ni, Cu, Ag, Pb, and Au, and coating materials such as SiO, SiO_2, BaF_2, and ZrO_2.

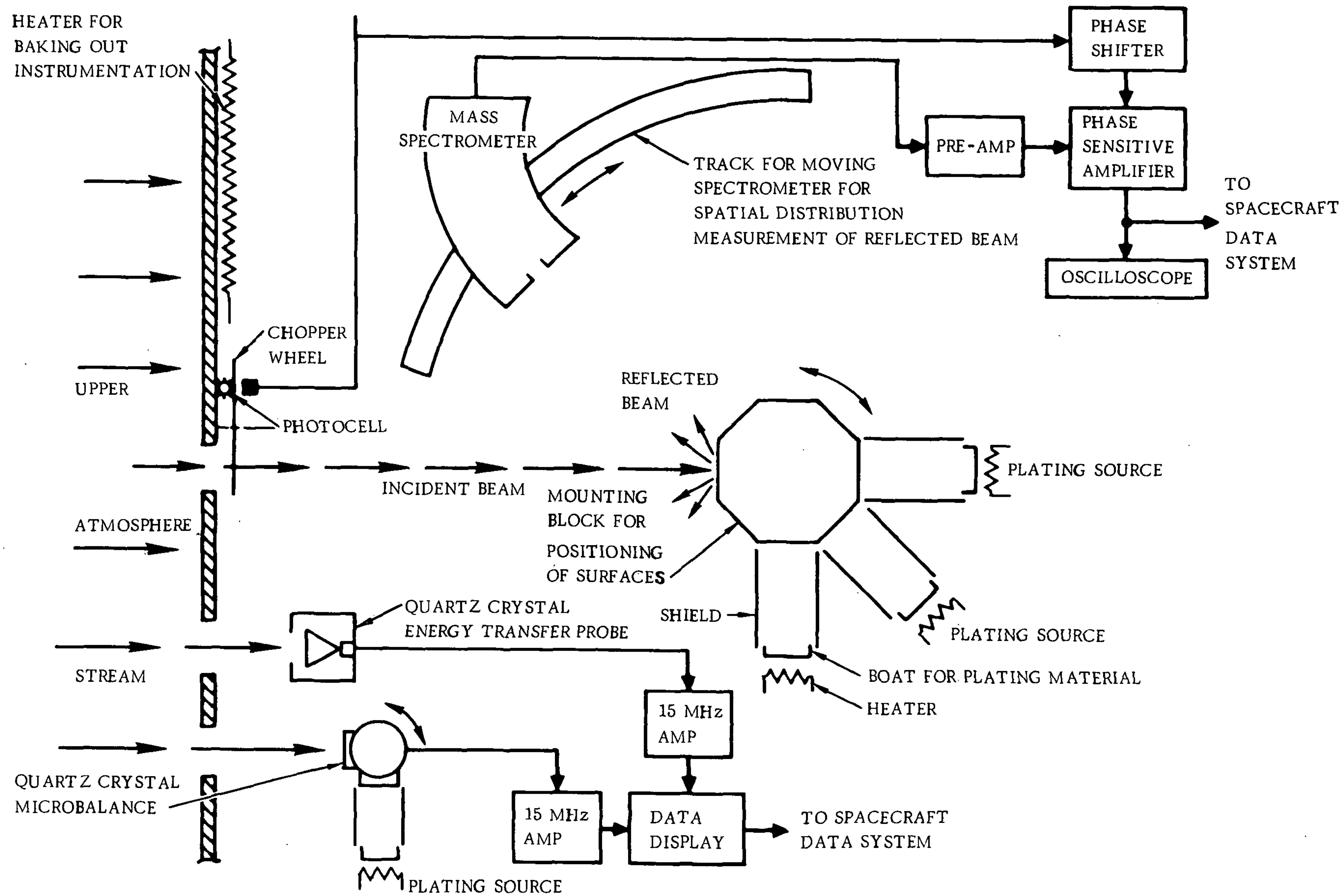


Figure 4-2. Schematic of Gas-Surface Interaction Experiment

Momentum transfer and energy transfer will be observed using the mass spectrometer to sweep through the airstream reflecting off of the test surface. The spectrometer will be adjusted to detect first O and then N_2 from the stream. By using the phase-sensitive amplifier to detect the time required for the stream to pass from the chopper to the target and then to be detected in the spectrometer, the change in momentum and energy of the stream resulting from the surface interaction will be found. Observing the spatial distribution of O and N_2 from the surface will give a second measurement of energy transfer. For complete accommodation of energy the reflected particles will have a cosine distribution. For zero accommodation, a specular distribution will result. Deviations from these two extremes will yield the degree of accommodation coefficients for the surfaces.

The recombination of O to O_2 on the surface will be found by measuring the fraction of O_2 present in the reflected beam in relation to the total intensity of O in the incident stream.

Chemisorption on surfaces will be found by measuring the buildup of mass for these surfaces plated in situ on the quartz microbalance.

Any outgassing contamination reaching the surfaces will be found by observing the mass loading of the quartz microbalance plated with Au.

After the equipment is in place, measurement should be taken periodically over one orbit.

4.4.2.4 Interface, Support and Performance Requirements. The support requirements for this experiment include the experiment equipment, the physics and chemistry airlock and associated extendable boom, the data monitoring device, and the data recording and telemetry facilities. The physical characteristics of the test equipment are:

	Mass kg (lb)	Volume m^3 (ft^3)	Power W
Mass Spectrometer	22.5 (50)	0.028 (1)	20
Quartz Microbalance	0.225 (0.5)	8 (0.3)	0.5
Energy Transfer Probe	0.225 (0.5)	8 (0.3)	0.5
Test Surfaces	2.25 (5)	0.014 (0.5)	-
Data Monitor	10.9 (24)	0.028 (1)	10

There will be twenty experiments run per three month period between resupplies.

The real time telemetry rate is 45 kilobits per second for this particular experiment. Assuming that a total of 130 surfaces are tested, the total data output would be 2.1 x 10^9 bits based on a one-hour exposure per surface. Total energy requirement would be 14.4 MJ (4 kW-hr.).

The requirement for the instrument package to be deployed ahead of the spacecraft structure while maintaining the windows normal to the incident airstream may require the spacecraft to maintain its attitude constant relative to the earth. If the space station is in the inertial-hold flight mode, the experiment package will have to be continually reoriented to maintain the pointing requirement. Pointing angle accuracy for this experiment is about 5.2 x 10^{-2} rad (3°).

There are no other known restrictions.

4.4.2.5 Potential Role of Man. In this experiment the astronaut must assume the role of experimenter. He must set up the experiment in the airlock and attach the platform to the extendable boom, operate the experiment, monitor, photograph and take notes on the observed data display. In addition he will be required to calibrate the instrument, change test surfaces, plate atomically clean surfaces, and reconfigure the experiment for the next run. He will also be required to oversee the data acquisition and organize the notes, film and data for shipment to the principal investigator.

4.4.2.6 Available Background Data

a. J. N. Smith, and H. Saltsburg, "Molecular Beam Scattering From Solid Surfaces," Fundamentals of Gas-Surface Interactions, H. Saltsburg, J. N. Smith, M. Rogers, Eds., Academic Press, New York, 1967, pp 370-391.

b. J. N. Smith, and W. E. Fite, "Recent Investigators of Gas-Surface Interactions Using Modulated-Atomic-Beam Techniques," Rarefied Gas Dynamics, J. A. Laurmann, Ed, Academic Press, New York, 1963, pp 430-453.

c. W. L. Fite, "Some Applications of Modulated Atomic Beam Experimentation," Proceedings of the Atomic and Molecular Beams Conference, Univ. Denver, Colorado, 1960, pp 7-48.

d. D. McKeown, and R. S. Dummer, "Gas-Surface Energy Transfer Experiment for OGO-F," IEEE Geoscience Electronics, Vol. GE-7, No. 2, April 1969, pp 89-106.

e. D. McKeown, and W. E. Corbin, Jr., "Space Measurements of the Contamination of Surfaces by OGO-6 Outgassing and their Cleaning by Sputtering and Desorption," Proceedings of the Space Simulation Conference, National Bureau of Standards, September 1970.

f. J. C. Zorn, G. R. Carignan, J. C. Pearl, D. P. Donnelly, and J. R. Caldwell, Laboratory Development of a Satellite Experiment For Gas-Surface Interaction Studies, University of Michigan, Contract NAS 8-21450, Report CR-61320, January 1970.

4.4.3 FLAME CHEMISTRY AND REACTION KINETICS AT ZERO-G

4.4.3.1 Objectives. The objectives of this experiment are: (a) the study of the kinetics and mechanism of combustion phenomena under essentially zero-gravity conditions; (b) elucidation of the contribution of the mass and thermal transport properties toward controlling the rate and mechanism of the combustion reaction; (c) the application of the results to explaining and predicting the course of the combustion reaction from a fundamental standpoint under all conditions after boundary conditions such as temperature, pressure, composition, extent of surface, gravity, etc., are specified.

Engineering design and basic scientific data on combustion phenomena will be obtained under essentially zero-gravity conditions in systems where gravity-induced convection effects make a predominant contribution to transport processes that control the rate and mechanism of the combustion. Emphasis will be placed on symmetrical geometry, but gas mass flow effects that could result from non-symmetrical combustion geometry will be studied systematically.

The resulting scientific data on reaction mechanisms, rates, free radical intermediates, and transport phenomena will be useful in understanding chemical reactions at all levels in the atmosphere, air pollution technology, fire protection, spacecraft component designs and safety procedures. Generalized mathematical models of combustion phenomena (for example, flame propagation rates and flammability limit profiles) in the absence of gravity-induced gradients will be developed which have practical engineering application.

4.4.3.2 Description. The approach taken will be to study the structure and radiation of the flame in detail. The structural phenomena concerns the determination of the composition and temperature of the flame at every point in the flame. The fuel-oxidant ratio, the initial temperature and the pressure will be specified or varied and information gathered on the energy and mass transfer as well as diffusion, conduction and convection effects. Correlation of this information will also lead to information relative to the kinetics of the reaction.

The following key techniques will be used to sort out the closely related phenomena and explain them.

4.4.3.2.1 Diffusion Flame Combustion. This technique involves the attainment of steady-state combustion in a slot burner through which separate but adjacent streams of oxidant and fuel are led to the combustion zone at the burner discharge. Under zero-g conditions the mass of the gases and the temperature of the flame will not contribute to the establishment of mass and thermal gradients which affect the structure and shape of the flame. Hence, diffusion properties will exhibit their great importance.

4.4.3.2.2 Premixed Flame Combustion. When the gases are premixed, the fundamental combustion rates uncomplicated by mixing processes will exhibit themselves. These rates will differ from gravity conditions because composition and temperature gradients caused by gravity will be absent.

The measurement, analysis and study of the steady-state gaseous diffusion flame and the premixed gas flame provide a firm but not an extensive basis for elucidating combustion phenomena. The burning of liquids and solids is also a familiar combustion phenomena. The relative mobility of these substances raises to importance heat transfer, heat of vaporization, and specific heat properties in regulating the nature, speed and course of the combustion reaction. The following additional types of systems will therefore be studied.

4.4.3.2.3 Liquid in Gas. Simple hydrocarbons will be burned in oxygen and oxygen-inert gas mixtures. The inert gases will be helium and carbon tetrafluoride which vary greatly in mass and specific heat.

4.4.3.2.4 Solid in Gas. Paraffin hydrocarbon, magnesium and aluminum metal and perhaps sulfur in oxygen, and oxygen-inert gas mixtures will be burned.

4.4.3.2.5 Wall Effects. A final parameter to be investigated will be the effect of walls. Present theoretical equations require a reaction to occur at any temperature above 0°K. Statistically, there is a finite probability that a sufficient number of molecules possess the required activation energy. The reason these thermodynamically possible reactions do not occur is believed to be due to the effects of surfaces and walls which leak off or otherwise dissipate the energy releases. This energy would otherwise accumulate to give a propagating reaction. The effects of the walls will be determined by carrying out the experiments in several sizes of containers and in the vacuum of space for especially energetic reactions.

Combustion produces a cloud or atmosphere of chemical free radicals surrounding the fuel mass. These free radicals are largely undisturbed in the absence of convection (zero gravity) and combustion proceeds then entirely through the diffusion process where oxygen diffuses inwardly to sustain combustion and products of combustion diffuse outwardly. Free radicals surrounding the fuel mass will be probed and analyzed using a suitable electron spin resonance (ESR) spectrometer coupled with a mass spectrometer. Alternately, a gas chromatograph coupled with a mass spectrometer will be used.

The experimental facility is shown schematically in Figure 4-3. The fuel and oxidant mixtures are prepared and stored in tanks. These mixtures are then led to a diffusion burner where steady-state combustion is set up and temperature, pressure, and composition measurements are made by means of probes in the flame. Simultaneously, still and motion pictures may be taken to delineate the visible structure on film and to document the experiment. The probe gases are led to a gas chromatograph and/or mass spectrograph for analysis. Flowmeters determine the gas flow rates.

Premixed gases are placed into tubes of increasing size. Ignition sources of known energy intensity are used to initiate the flame. Temperature probes, cameras and light detectors are used to determine the energy of ignition, flame speed, and flame shape.

A systematic execution of the experiments using a matrix of fuels, fuel-oxidant ratio diluents and operating conditions will be performed. Probes will sample the flame for the temperature and composition profile. These data, together with a consideration of the initial conditions and application of conservation of mass and energy and continuity equations, are sufficient to yield mathematical models of combustion phenomena. From these models there can be deduced the reaction rates, propagation mechanism, flammability limits, and heat and energy sources and sinks which control

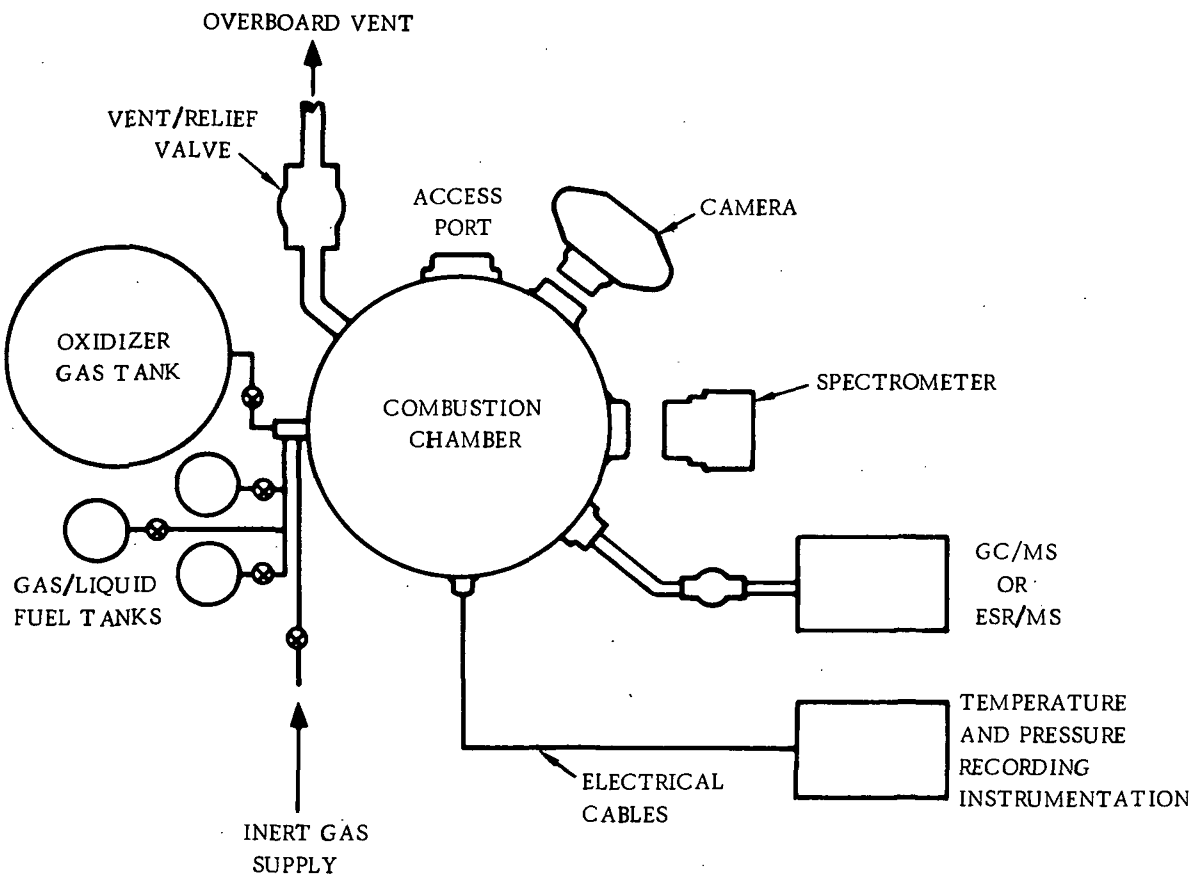


Figure 4-3. Zero-g Combustion Experiment Schematic

the combustion process. When these things are understood, there will be a sound basis for design, construction and use of reactions involving processes used in the technologies of combustion, propulsion, fire protection and prevention, air pollution, and general fire safety.

4.4.3.3 Observation/Measurement Program. The chief observations and measurements required for this program are gas flow rates, liquid flow or regression rates and solid surface regression rates. For steady-state diffusion flames, these measurements must be made for each fuel-oxidant ratio at various pressures. The initial gas temperature may also be varied for an extended program.

Parameters to be measured are:

a.	Temperature:	Thermocouples
		Optical Pyrometers
		Cameras with variable density filters
b.	Pressure:	Pressure Transducers
		1. Piezo electric
		2. Strain gage
c.	Composition:	Electron Spin Resonance Spectrometer/Mass Spectrometer.
		Gas Chromatograph/Mass Spectrometer.
d.	Fuel Quantity:	Liquid
		1. Displacement of syringe-type injector
		2. Positive displacement flow meter
		Solid
		1. Volume measurement
		2. Mass measurement
		Gas
		1. Pressure drop across calibrated orifice
		2. Positive displacement flow meter
e.	Oxidizer Quantity:	Liquid, Gas } Same methods as for fuel

f. Combustion Geometry: Still Photographs

Motion Pictures

The measurement ranges and the accuracy required for these measurements will be:

a.	Temperature:	291 to 1373 ±3.6°K (40 to 200 ± 2°F)
		1373 to 3043 ±9°K (2000 to 5000 ± 5°F)
b.	Pressure:	0.35 kN/m^2 (0.05 lb/in^2)
c.	Composition:	Resolve type to 1 amu over range of 0-100 amu.
		Resolve quantity to 1 ppm.
d.	Mass:	1 milligram
e.	Time:	1 millisecond
f.	Position:	0.0254 cm (0.01 in.)

Measurements of temperature, pressure, and composition will be made continuously during each experiment run.

During the experiment, photographs will be made of the flame and the interior probed for composition and temperature. The probe gases must be quickly quenched to maintain their composition and analyzed by means of gas chromatography and mass spectroscopy.

The flame speed must be measured for premixed gases burning in a tube. This may be done photographically and/or thermally or by the use of phototubes to measure the radiation.

For meaningful results, the initial gas or fuel temperature must be known or kept constant by thermal control equipment and insulation.

It is assumed that a total of ten fuels and five oxidant/inert gas ratios and five operating conditions (temperature, pressures, etc.) will be used in performing this experiment. Each test will last two hours; including setup time. Total experiment operating time is 500 hours.

The validity of the hypothesis that free radicals formed in the flame front are the species which control the propagation of the flame by regulating mass and energy transfer can be checked by the use of an electron spin resonance apparatus. This instrument measures the concentration of free radicals in a flame.

The data for the combustion processes occurring under gravity conditions is now fairly well known for laminar flames (as opposed to turbulent flames). Comparison of results with those determined under zero-gravity conditions will provide data for establishing the theory of flames on a firmer basis. It will do this by revealing the significance of free radicals, mass transport, and thermal transport in explaining flame propagation phenomena.

4.4.3.4 Interface, Support and Performance Requirements. This experiment will require a crew member to perform as an active experimenter during the conduct of the experiment. He must set up the initial conditions, calibrate the instrumentation, initiate the different steps in the experiment and examine the preliminary data to determine its validity.

The physical characteristics of the experiment equipment are shown in Table 4-3. The total energy required for the experiment is 550 MJ (155 kW-hr) based on the 500-hour operating time.

Table 4-3. Experiment Equipment Characteristics

	Power W	Mass kg (lb)
Mass Spectrometer	50 W	6.8 (15)
Camera	200 W	6.8 (15)
Gas Chromatograph	200 W	6.8 (15)
Pyrometer	10 W	6.8 (15)
Data display and interface	50 W	9 (20)
Experimental Setup	-	45 (100)
Fuels and Oxidant	-	135 (300)

The data from this experiment consists of ten temperature measurements, two mass spectrograph measurements, two pyrometer measurements, six flow and eight pressure measurements and five miscellaneous measurements. During each two-hour test period these measurements will be made at a rate of 5000 samples per second for a total bit rate of 2×10^6 bits per second. Assuming a 30-minute measurement time, the total data output is 0.9×10^{12} bits

During the test runs the g level must be held at 10^{-4} g or less.

The thermal output from this experiment is primarily hot gases most of which will be vented into space. It is assumed then that thermal control will not present a significant problem.

4.4.3.5 Role of Man. The experimental gas mixtures may be prepared on Earth or they may be mixed just prior to use. A crewman will be required to initiate each experiment and monitor the performance for proper execution.

The crewman will require sufficient indoctrination in combustion and flame chemistry to understand the significance, purpose and use of the data. He should then be capable of adjusting faulty or malfunctioning equipment so that the desired data may be obtained. To achieve this the man must be skilled in optics and electronic instrumentation including mass spectrometric and gas chromatographic apparatus.

The crewman will also require sufficient knowledge of chemistry and combustion that he will safely handle combustible and explosive mixtures of gases, liquids, and solids.

4.4.3.6 Available Background Data. Although the amount of information relative to flame chemistry is voluminous for flames under one-g gravity conditions (Lewis and von Elbe, "Combustion, Flames, and Explosion of Gases," 12 International Symposia on Combustion, etc.), there is very little known about the behavior of flames under zero-gravity conditions. Probably nothing is known about the detailed flame structure under zero-gravity and how it differs from one-g gravity conditions. This is because only short duration drop tests have been performed on parabolic flights in airplanes of too short a duration to allow probing and analysis of the flame. These short duration tests have demonstrated, however, that combustion processes under zero-gravity conditions are significantly different from those observed on Earth.

Unfortunately, no tests made from drop towers or in airplanes are of sufficient duration to provide any basic information. The desired data would lead to the means for discriminating the influence of mass or particle diffusion, radical transport or thermal diffusion in explaining flame propagation processes.

a. Earth Orbital Experiment Program and Requirements Study, Experiment Description Data Sheets for Research Group Cluster 4-p/c-1, Effect of the Space Environment on Chemical Reactions (MDAC).

b. General Dynamics/Convair Final Technical Report, Study of Zero Gravity Capabilities of Life Support System Components and Processes, NASA CR 66534, Feb. 1968.

c. W. F. Wilhite, The Development of the Surveyor Gas Chromatograph, JPL Technical Report No. 32-425, May 15, 1963.

d. The techniques of examining chemical free radicals in flames on earth have been worked out by Professors Fristrom and Westenberg at Johns-Hopkins University. These techniques are currently in process of being checked at MSC, using earth-based ESR equipment manufactured by Perkin-Elmer. Specific references to these investigations are not available.

e. T. H. Cochran, and W. J. Masica, "Effects of Gravity on Laminar Gas Jet Diffusion Flames," Le RC Technical Note NASA TN D-5872, June 1970.

4.4.4 CHEMICAL LASERS

4.4.4.1 Objective. The objective of this experiment is to determine the operating characteristics of self-pumping chemical lasers under zero-gravity conditions. Data and observations resulting from this experiment will be utilized in the development and optimization of chemical lasers for space applications.

This experiment demonstrates a transition from scientific research to technology applications. In some respects, it closely parallels the flame chemistry and reaction kinetics scientific investigations described in Section 4.4.3, but it extends the fundamental combustion data to those parameters required for engineering design. The experiment also includes evaluation of the applicability of the chemical laser for space communications and an assessment of its potential contamination effects.

Chemical self-pumping or self-sustaining lasers may be used efficiently in a zero-gravity environment to provide a high energy density, optical beam for the transmission of energy over long ranges and as the carrier for long distance communications systems. Under zero-gravity conditions the conversion of chemical energy in the combustion process to electromagnetic energy (photons) should be highly efficient as compared to optical and electromagnetic pumping techniques commonly used in solid state and gas lasers.

In a chemical laser, large amounts of chemical energy are released during a combustion process and converted to electromagnetic energy (photons). A high population density of excited reactive chemical species (molecules, atoms, and ions) is produced in an optical cavity during the combustion process. These species are stimulated in the cavity to release energy in the form of coherent light. The result is a very high energy density optical beam.

In a gravitational field, the combustion process is governed by both convection and diffusion, whereas under zero-gravity conditions only the diffusion process is operable. As a result, under zero-gravity conditions, high concentrations of ions, produced by chemical reactions during the combustion process, remain in close proximity to the fuel. Little energy is converted into translation as is the case in a gravitational field where convection takes place. The majority of the energy released by the combustion process is available in the form of excited optical states of reaction species for the production of a coherent light beam when the reaction species are properly simulated in a laser cavity. The emission of coherent light by the reaction species may be either self-stimulating or stimulated by an electric field.

For example, in a gravitational field, a polycarbonate polymer burns in oxygen to produce an intense yellow light and considerable heat. In a zero-gravity environment, this polymer burns with an intense blue light release and little heat is released. In the former case, ions formed in the combustion process rapidly re-combine with oxygen aided by the convective coupling mechanism. In the latter case, the reaction species remain in high concentrations close to the fuel with little of the reaction energy being converted into translation. The basic chemical reactions are the following:

$$\text{Polymer} + O_2 \rightarrow CO + \text{energy}$$

$$CO + O \rightarrow CO_2 + h\nu \text{ (light, in zero gravity).}$$

4.4.4.2 Experiment Description. An experimental chemical laser will be delivered as a "suitcase" type payload for evaluation in the physics and chemistry laboratory. This laser will initially be operated and tested on Earth using an electric field to stimulate laser action. Measurements of beam intensity and laser efficiency will be made in the Earth's gravitational field.

The laser will be installed and operated under zero-gravity conditions with and without electric field stimulation. Measurements of beam intensity and laser efficiency will be made under zero-gravity conditions for comparison with 1-g performance. The products of combustion must be exhausted to the space environment and are a potential source of spacecraft contamination. A test sequence will be performed with subsequent contamination monitoring to evaluate possible contaminating effects of discharged exhaust products on spacecraft exterior surfaces.

4.4.4.3 Observation/Measurement Program. The intensity of the laser beam will be determined by configuring an optical calorimeter to intercept the entire beam. Laser efficiency will be computed from a knowledge of the energy released by the fuel and oxidizer during combustion and the intensity of the laser beam. The thermal energy loss by conduction and radiation, and the energy content of the exhaust products will be determined to assist in evaluation of the laser design. The temperatures within the laser cavity, of the exhaust products, and of the exterior of the laser will be continuously monitored by thermocouples and recorded. A mass spectrometer will sample the exhaust from the laser to determine the concentrations of exhaust products, and the mass flow of the exhaust will be computed from the exit nozzle characteristics.

Sample coupons, representing optical and thermal control surfaces, will be located on the exterior of the physics and chemistry lab. These coupons will be retrieved after the experiment and examined for contamination effects.

The duration of each laser experiment is approximately two hours. A total of 15 temperature measurements, three pressure measurements, two spectrometer measurements and two calorimeter measurements will be made during each test.

4.4.4.4 Interface, Support, and Performance Requirements. The gravitational field during the experiment should be limited to no more than 10^{-2} g to provide continuous laser action.

The laser cavity will contain exhaust valving automatically controlled by temperature and pressure sensors to alleviate the hazards associated with flame containment in the event of uncontrolled combustion. In addition, fire detection and extinguishment equipment must be available in case of an uncontrolled fire. Sample coupons for contamination monitoring will be installed on the outside of the physics and chemistry lab before each experiment and will be retrieved for evaluation at the conclusion of each experiment.

Size, weight and power requirements for stores and instrumentation are listed in Table 4-4.

Total energy requirement for the experiment is estimated to be 25.2 GJ (7 kW-hr) assuming a total of 50 experimental runs is made. The data rate is assumed to be 10^4 samples per second per channel for a total rate of 2.4×10^6 bits per second. The total data for the test is 0.9×10^{12} bits.

4.4.4.5 Potential Role of Man. Man will calibrate instrumentation for this experiment and monitor the laser operation during the experiment. The scientist/astronaut will install fuel and oxidizer, and sample coupons on the spacecraft exterior. At the end of each experiment, he will retrieve sample coupons and make contamination measurements on them.

Table 4-4. Experiment Equipment Physical Characteristics

	Weight kg(lb)	Volume $m^3(ft^3)$	Power W
Polycarbonate Fuel Rods	45 (100)	0.028 (1)	-
Oxygen	90 (200)	0.225 (8)	-
Contamination Coupons	0.225 (0.5)	0.0028 (0.1)	-
Laser Cavity	68 (150)	0.014 (0.5)	5
Mass Spectrometer	6.8 (15)	0.014 (0.5)	10
High Voltage Power Supply	6.8 (15)	0.028 (1)	15
Optical Calorimeter	9 (20)	0.028 (1)	10
Data Recorder	22.5 (50)	0.056 (2)	30

4.4.5 QUANTUM EFFECTS AT LOW TEMPERATURE AND ZERO-g

4.4.5.1 Objective. The objective of this experiment is to study the unusual hydrodynamics and thermodynamics of superfluid drops. The hydrodynamics of superfluid drops is not only of interest in its own right, but may also shed light on the dynamics of nuclear fission and the hydrodynamics of pulsars.

The "weightless" environment of space is ideal for extensive experiments on superfluid drops. The time and equipment required for forming the drops, making them superfluid, and then setting them into oscillation rule out the use of a drop tower. Moreover, in a space vehicle, the cold liquid helium can easily be pumped and so made superfluid by simple venting to space.

Techniques to be developed in the design and performance of this experiment for handling, and even manufacturing, superfluid helium in space,will be useful for future space missions. The use on future missions of: (a) large superconducting magnets needed to measure energetic particles; (b) Josephson junctions to measure small magnetic fields; (c) Josephson junctions to measure infrared radiation; and (d) cooled maser amplifiers to measure microwave radiation, all will require use of liquid helium. There are advantages to having the liquid helium in its superfluid form. Superfluid helium, unlike ordinary liquid helium, will not boil — it is a "quiet" liquid — and moreover is a better conductor of heat than is ordinary liquid helium. Provision can be made, if desired, to extend a portion of this experiment into an engineering experiment to design and study a superfluid cooling system that can operate in space.

The apparatus used to study the hydrodynamics of superfluid drops can be used to study hydrodynamics of ordinary fluid drops. Study of the ordinary fluid drops can be used as a "shakedown" experiment for the main experiment, and will provide a comparison for the behavior of the superfluid drops.

4.4.5.2 Description. In the experiment, several phenomena — rotation of the drop, its free oscillation, and its fisson — will all be studied. By observing these phenomena, one can infer such quantities as critical velocities, surface tension, normal-fluid superfluid friction, configuration of the vortex array, and the coupling between the collective oscillations of this array and the free oscillations of the drop. All these quantities will be determined as a function of drop size and drop temperature. Circulation patterns and vortices will be observed by looking at the motion of hydrogen snow or other snows within the drop.

The drop will be electrically charged. This will be done mainly to help keep the drop positioned within the apparatus by means of applied electric fields. However, having the drop charged is useful in other ways: (a) oscillating electric field gradients can be used to excite both free and forced oscillations of the drop, and also to damp any free oscillations that may be produced when the drop is formed; (b) the effect of surface charge on surface tension can be observed; (c) the drop can be made to "rotate" by first deforming the drop by applying a field gradient and then rotating this gradient; and (d) the drop can be made to fission by applying a sufficiently large field gradient. All these, with the obvious exception of (b), can be accomplished in other ways, however. Oscillations can be excited by the energy provided by sound waves excited in the helium gas in which the drop is suspended. Vortices generated by rotation can be generated instead by superconducting particles suspended in the drop. Strong magnetic fields will cause these particles to rotate within the drop and so generate vortices. Magnetic field gradients can then be used to sweep the particles out of the drop, if required. Finally, fission of the drop will take place if the surface oscillations of the drop are driven sufficiently hard.

The surface oscillations of the drop will be used to determine: (a) the surface tension of the drop; (b) the mutual friction of the normal and superfluid components; (c) critical velocities, and (d) coupling between the surface modes and the collective modes of the vortex array. The surface tension helps determine the frequency of the surface oscillations so that by measuring this frequency the surface tension can be deduced. The mutual friction of normal and superfluid components can be measured by observing the damping of the free oscillations of the drop, or by observing the amplitude of forced oscillations. Critical velocities are determined by increasing the amplitude of surface oscillations until the flow pattern indicates the formation of vortices. The coupling of the surface modes to the collective modes of the vortex array is ascertained by driving the surface modes and observing the resulting motion of the vortices.

The rotation of the drop will also be used to determine critical velocity for formation of vortices. Once the vortices are formed, their array will be observed as a function of their number. Coupling between surface modes and collective modes of the array will again be studied, but this time by driving the system at the eigenfrequencies of the array and then observing amplitude of the resulting surface oscillations. The system can be driven by sound waves, by electric oscillations, or by magnetic field oscillations applied to superconducting particles when these are used to generate vortices.

4.4.5.3 Observation/Measurement Program. It is envisioned that approximately 25 liters of liquid helium will be needed for the superfluid helium drop experiment. The helium can either be brought up in a Shuttle, contained in a storage dewar in the liquid state, or can be liquified aboard the orbiting spacecraft from the gaseous state using a three stage cryostat (Reference a). Use of the cryostat has the advantage that the liquid helium can be produced at any convenient time, unlike use of the storage dewar which would require the experiment to be conducted within two or three days of the time that the liquid helium was brought aboard. The disadvantage of the cryostat is the additional weight required for the storage of pressurized gas and the weight of the cryostat itself.

A few hours prior to starting the experiment the liquid helium will be cooled to its superfluid state by using the vacuum of space to pump on the liquid helium and lower its temperature.

The dewar aboard the spacecraft will serve the dual purpose of storage dewar and experiment dewar. The experiment dewar will be constructed around a cubical container in which the experiments are performed. The container, 10 cm on the side, will have as its sides electrical plates, each side electrically insulated from the others allowing separate voltages to be applied to each side. Two view ports, each through an adjacent side, will give visual access to the center of the cube. The cube will be vacuum tight so that low pressures can be maintained within it. The stored superfluid helium will cool the walls of the cube to approximately 1.0°K and will also be used as a source of helium for formation of the drops.

The superfluid helium drop will be formed and inserted into the experimental region with a device similar to a hypodermic syringe. The syringe will have a diaphragm such that a force on the diaphragm will force a helium drop through the needle of the syringe into the experiment region. Electrical charge will be placed on the helium drop by charging the syringe. The charged drop will then be positioned in the center of the experimental chamber by controlling the voltages on the sides of the cube. Snow required to observe circulation within the drop will be suspended in the drop by bleeding hydrogen gas into the syringe. The drop will be viewed by the astronaut through the view ports in the chamber. Mirrors will be used to view both ports simultaneously. The astronaut will adjust the voltages on the side plates for accurate postioning of the drop. After the drop is properly aligned, the astronaut will position the high-speed (400 frames per second) motion picture camera used in recording the data.

The drop will be set into oscillation by placing audio frequency voltages on the side plates of the cube so that alternating electric field gradients will induce force gradients on the drop.

Internal flow patterns within the drop will be monitored visually by the astronaut and photographically by observing the motion of solid hydrogen snow dispersed in the superfluid helium. Changes in the internal flow pattern will be observed as various modes of oscillation of the drop are driven by the alternating electric field gradients. Selected modes of oscillation will be driven to sufficiently large amplitudes so as to observe fissioning of the superfluid helium drop. Internal flow patterns will be observed before and after fissioning. An alternate method of fission of the drops will be to place a static field gradient on the drop of sufficient magnitude so as to pull the drop apart.

The superfluid drop will be rotated by placing very small superconducting spheres within the drop. A magnetic field will be imposed on the spheres by superconducting coils that are inside the dewar. The magnetic field will cause the spheres to rotate and impart rotation to the helium drop. The vortex motion within the superfluid helium drop will then be observed by monitoring the motion of the hydrogen snow suspended in the drop. An alternate method of producing rotation will be to sweep the electrical field in a circular motion so that the field will act on the charged drop and cause it to rotate. Coupling between the vortex motion in the drop and surface oscillations will be measured by simultaneously exciting oscillations and vortices in the drop. Motion of the vortex lines which will be coupled to the rotating superconducting spheres can be observed by linear movement of the spheres perpendicular to the vortex lines. The superconducting spheres which have a magnetic moment can be moved by magnetic field gradients produced by small superconducting coils located within the experimental cubical cavity. In this manner coupling between the vortex lines and the surface modes can be measured.

A series of intital test runs will be made to validate the drop forming and charging techniques. Following this, attempts to obtain superfluid helium drops would be made and then initial efforts to induce spinning and vortex formation will be made. The photographic techniques will be proven at this point and preliminary test runs on both spinning and oscillating drops made.

Following review of this data, a comprehensive series of test runs will be conducted in which temperature, pressure, charge, charge oscillation and magnitude, and magnetic field will be varied in a systematic fashion. A total of 50 test runs will be made. Each run will require about three hours. One run will be conducted per day.

Experiments on weightless normal fluid drops formed from materials such as mercury, various organic liquids, or water can also be conducted in the experimental chamber used in the superfluid helium experiment. Finely divided aluminum powder could be mixed in with transparent liquids so that flow patterns could be observed in the drops. The electrostatic positioning controls and the data acquisition procedure could be used in both types of experiment.

4.4.5.4 Interface, Support and Performance Requirements

4.4.5.4.1 Crew Support. This experiment will be set up, operated, and results evaluated by a crewman. Due to its fundamental nature, a physicist may be necessary to conduct the experiment.

4.4.5.4.2 Size and Weight. The experiment apparatus consisting of the dewar containing the experiment chamber, superconducting magnet coils, electrostatic positioning plates, etc., will be approximately a cube, 1 meter (3.3 ft) on the side and will weigh about 50 kg (110 lb) with the liquid helium included. The size and weight of the source of liquid helium are not included in these figures.

4.4.5.4.3 Power.

a. 1500 W for superconducting magnet for generation of vortices by means of superconducting spheres. Power is required for several minutes at a time, not continuously operated.

b. 200 W for illumination of drops (photography). Power is required for several minutes at a time, not continuously operated.

c. 100 W for power supplies for: voltage on balancing plates, temperature measuring devices, etc. Continuous demand while the experiment is being carried out.

d. 100 W for solenoid valve control on cryostat. Intermittent use (0.5 hour at a time).

e. No power for liquid helium generation. The helium will either be brought up to the orbiting spacecraft as a liquid, or will be made aboard the spacecraft by a three stage liquefier. The liquefier uses the expansion of compressed N_2 to cool compressed H_2, whose expansion, in turn, is then used to liquefy the He. See Reference (a).

4.4.5.4.4 Data. Data from the experiment will consist primarily of cine film. Approximately 3600 meters (12,000 ft) of film will be required which will weigh 30 kg (66 lb) and occupy 0.01 m^3 (0.4 ft^3).

Test parameter data such as temperatures, pressure, charge, and magnetic field vectors, will be acquired by the laboratory data acquisition system. The data rate will be approximately 10 kbps.

4.4.5.4.5 Environment. The laboratory facility must provide an appropriate vacuum venting system for evacuating the experiment apparatus.

During the conduct of the experiment the gravity level must not exceed 10^{-4} g at the experiment apparatus/work station interface.

4.4.5.5 Potential Role of Man. A trained astronaut will be needed in all phases of this experiment. He will have to insert and position the superfluid helium drop in the experimental chamber after he has determined that the drop is of sufficient size for the experiment. If the drop is too small, he will sweep the drop to the wall of the chamber with electric fields and reinsert another drop. The astronaut will be required to observe the snow in the drop and determine if it is of sufficient density for the motion picture photography which will be used to observe oscillation, flow pattern, and vortex formation. The astronaut will have to decide when adequate data has been obtained in each of the various phases of the experiment.

4.4.5.6 Available Background Data. The hydrodynamics of superfluids, such as He II and neutron matter, Reference (b), is quite unlike that of ordinary fluids. Superfluids, unlike ordinary fluids, tend to exclude vorticity. In fact, vorticity is completely excluded except when velocities in the fluid exceed critical values. When such velocities are exceeded, vorticity can appear in the fluid, but only in the form of discrete quantized vortices. Vorticity of the superfluid can increase only if the number of quantized vortices in the superfluid increases.

Heretofore, the hydrodynamics of superfluid helium have always been observed with the superfluid enclosed in a container. In the present experiment, the hydrodynamics will be observed in a free drop. The only surface is then the free surface, and vorticity cannot be introduced, as it usually is, through relative motion of the superfluid helium and the container walls. Vortices can only be introduced by relative motion of different portions of the superfluid itself. Consequently, this experiment — the first to measure critical velocities of superfluid helium in the absence of constraining walls — will help answer the question (Reference c): What role do such walls play in the generation of vortices?

The collective oscillations of the vortex array present in a rotating superfluid drop may shed light on a phenomena observed in pulsars. Ruderman (Reference d) has proposed that an observed periodic change in the frequency of radiation emanating from pulsars is due to collective oscillations of the superfluid vortex array in the pulsar. The vortices are those present in the neutron superfluid in the pulsar. Ruderman's proposal has been examined by Fetter and Stauffer (Reference e) and by Greenstein (Reference f). While it is certainly true that the helium drop is far from a faithful analog of a pulsar, questions can be asked of the helium drop that have relevance for the pulsar. First, what is the vortex array for a superfluid sphere? Second, in a true eigenmode of a superfluid sphere, how much of the mode is vortex mode and how much is surface mode? Finally, what are the conditions which cause the vortex array in the sphere to become random, resulting in a condition of superfluid "turbulence"?

Fission of superfluid helium drops is also an interesting phenomenon. Vortices form in the drop as fissioning proceeds and the vortices, once present, may then affect subsequent stages of fission. For example, asymmetry in drop fission may arise. The first vortex to be formed in the fissioning drop can appear in only one-half of the drop, wherupon the two halves are no longer symmetric. The half with the vortex should evolve differently from the half without the vortex. Consequently, once fission is complete, the two drops should be of different size, and have different vorticity. The dynamics of an asymmetrically fissioning charged drop are of some interest in nuclear physics. One model for a nucleus is, of course, the liquid drop model. The dynamics of fissioning nuclei have been studied using computer simulation of the fissioning process. However, it is felt that the simulation is accurate only in describing the initial stages of fission (Reference g). If in this experiment asymmetric fission of an electrically charged drop can be produced, a more realistic description of the later stages of nuclear fission can be provided; at the very least, the data can be used to test the applicability of the liquid drop model of nuclear fission (References h and i).

References

a. Air Products and Chemicals, Inc., Allentown, Pennsylvania. Model AC-36 Cryo-Tip Refrigerator.

b. G. Baym, C. Petick, and D. Pines, Nature, 224, 673, (1969) and references given there.

c. See, for example, Wm. E. Keller, Helium-3 and Helium-4 (Plenum Press, New York, 1969). Chapter 8.

d. M. A. Ruderman, Nature, 225, 619 (1970) and Nature, 225, 338 (1970).

e. A. L. Fetter, D. Stauffer, Nature, 227, 584 (1970).

f. G. Greenstein, Nature, 227, 791 (1970).

g. Private communication from G. Swiatecki to E. Haines.

h. T. Kitchens, W. A. Steyert, and R. D. Taylor, Phys. Rev. Letts. 14, 942 (1965).

i. W. A. Steyert, R. D. Taylor, and T. Kitchens, Phys. Rev. Letts. 15, 546 (1965).

4.4.6 GAS REACTIONS IN SPACE

4.4.6.1 Objective. The objective of this experiment is to obtain and analyze data associated with the ionization, dissociation and chemi-luminescence of chemical compounds which are exposed to the space environment. Chemicals (gases and compounds) released at orbital altitudes are subject to reactions with upper atmospheric constituents (primarily atomic oxygen) and are exposed to the extreme ultraviolet (EUV) radiation in the solar spectrum. Releases in the trapped radiation belts afford exposure to the electron and proton fluxes encountered in this region of space. The ionizing effects of X-rays may be observed by releases during periods of high solar flare activity. Chemical compounds exposed to the EUV undergo excitation, ionization and dissociation processes. In addition, chemical reactions which can result in optically and vibrationally excited states may take place in the presence of atmospheric constituents. Typical of these mechanisms at orbital altitudes are photodissociation, photoionization, recombination, ion- and atom-molecular reactions, electron attachment and detachment, charge exchange reactions, and three body reactions.

Such reactions may be observed using optical and mass spectrometers, and electrometers to provide data from which reaction rates, species concentrations, and electron/ion concentrations may be determined. The observed optical intensities will be a function of species concentrations and reaction rates. The spatial dispersion of high-altitude releases, observed photographically, is a function of upper atmospheric motion and the containment of electrons and ions by the ambient geomagnetic field.

At orbital altitudes, the atmosphere is optically thin. At these altitudes, spectroscopic and photographic observations of chemical releases will contain spectral regions not obtainable in ground observations, and will be essentially free of atmospheric attenuation, scintillation and noise. Such observations may be correlated with simultaneous ground observations and the results of the correlations used to revaluate previous data obtained by means of rocket releases and ground/airborne observations.

Gases can be released in such a manner as to form condensates such as snows. The sublimation and excitation of these snows by solar radiation will simulate the desorption of gases from comets and planetismals. The mechanism of sublimation and the resultant chemistry can be followed photometrically. Various mixtures of gases can also be exposed to solar radiation in confining vessels of the appropriate design for transport to Earth and subsequent laboratory analysis. These experiments will provide information on the synthesis of minute quantities of organic chemicals from simple gases in the primordial dust cloud and in interstellar space by solar irradiation. Gas release and closed vessel irradiation experiments will supply data on the interaction of the solar electromagnetic spectrum with matter which is of utmost significance with respect to the chemical history of the solar system.

Release at different altitudes and under different solar illumination conditions will provide information on the temperature dependence of reaction rates and on the number, densities and temperatures of atmospheric constituents.

4.4.6.2 Experiment Description. Gases and other chemical compounds will be released from cannisters remote from the orbiting spacecraft. These releases may be of two types: by cannister disassociation to form a cloud, and through a nozzle on the cannister to form a trail. The cannister material should be of a type which sublimates after several hours exposure to UV radiation to eliminate it as a source of debris. In both cases, the releases must be made sufficiently distant from the spacecraft to insure that no interaction occurs between the spacecraft and the environment in its immediate vicinity. Environmental contamination in the vicinity of the spacecraft resulting from waste dumps, thruster operation, escaping gases, etc., must be avoided to prevent both contamination of and reaction with the released chemicals. Ionizing radiation emanating from nuclear power sources and high intensity electric fields in the spacecraft vicinity must also be avoided. Photographic and spectroscopic observations of the releases will be made from the space laboratory. Mass spectrometer, electron probe, electric field and temperature measurements will be made by a free-flying sub-satellite or by a long boom, configured with appropriate instruments, which would probe the release or the boundary of the cloud or trail. Data obtained by these instruments will be returned to the space laboratory for recording. The operation of the sub-satellite or articulated boom is constrained by the same contamination considerations that apply to the spacecraft.

The background solar EUV spectrum and flux, and particulate radiation spectrum and flux will be determined by photometric/dosimetric instruments aboard the space laboratory and/or sub-satellite. Ground spectroscopic and photographic observations of the releases may be made coincident with space laboratory observations. Time synchronization of the space laboratory and ground station is necessary. The times of observations must be recorded with all data.

Gases in closed vessels may be exposed to solar irradiation by deployment through an airlock on a platform which is driven for solar tracking. Absorption or emission spectroscopy, either UV, visible, or infrared, can be performed during exposure by mounting the vessel within an appropriate spectrometer on the airlock deployment platform. Thin aluminum vessels with windows of LiF or other appropriate materials will be used.

Data reduction and analysis will be accomplished on the ground upon return of the data from the orbiting space laboratory.

4.4.6.3 Observation/Measurement Program. Typical of the chemicals to be released are gases (e.g., NO and acetylene) and compounds (trimethylaluminum, diborane and BaO). The chemicals will be provided in cannisters for ejection from the space laboratory. Gases will be released by cannister disassociation or through a nozzle on the cannister. Chemical compounds will be released through a nozzle by means of a combustion process.

Scanning spectrometers covering the wave length range from the EUV to the near infrared will record the characteristic emission lines from excited optical states of ions and neutral species in the cloud, as a function of time. Visible cine-photography will be used to record the history of cloud dispersion as a function of time.

An EUV spectrometer and photometer will record the solar flux and spectrum during the observation period. Similarly, an electron probe will observe the ambient electron flux and spectrum.

The duration of optical observation will be limited by the dispersion/diffusion characteristics of the cloud, emission line intensities, field of view of optical instruments, and relative velocity of the cloud with respect to the spacecraft. Experiment optimization should permit observation times of the order of ten's of minutes. The number of exposures is assumed to be 20, for a total experiment duration of 200 hours.

During the experiment, the sub-satellite or articulated boom instrumentation will traverse through the cloud or along its boundary to permit observations by mass spectrometer, electron probe, electric field and temperature instrumentation. The data obtained from these instruments will be transferred to the spacecraft, where it will be recorded along with other data. The sensing instrument package should have a very low relative velocity with respect to the cloud to permit maximum parameter observation. Timing signals must be recorded along with all instrument output data.

Careful experiment design and coordination will permit simultaneous spectroscopic observation of selected releases by ground/airborne stations.

4.4.6.4 Interface, Support, and Performance Requirements. Canisters of chemicals for release will be stored in the space laboratory. The EUV spectrometers and photometer must be mounted and operated exterior to the spacecraft as must the electron probe. The near UV, visible and near IR instruments and photographic equipment can be mounted inside the space laboratory, observing the releases through viewports which will adequately transmit these spectral regions.

The sub-satellite or articulated boom must be configured in a manner providing direct exposure of the instrument probes to the cloud. The location and attitude of the experiment instrumentation must be under the control of the space laboratory during the experiment. Data from the instrumentation will be acquired at a data rate of about 1 kbit/sec.

The chemical release must take place sufficiently far from the spacecraft to assure no contamination or other disturbance of the cloud. Thruster operation on the sub-satellite, if used, must take place sufficiently far from the cloud to preclude contamination.

All data obtained from the experiment instrumentation must be recorded, with timing signals, for transmission to Earth.

Size, weight and power requirements for instrumentation are:

	Weight kg(lb)	Volume $m^3(ft^3)$	Power W
Spacecraft			
Cannisters	57 (125)	0.027 (1)	-
EUV photometer	1.1 (2.5)	0.0054 (0.2)	0.5
Electron probe	2.25 (5)	0.027 (1)	10
EUV spectrometers (2)	22.5 (50)	0.054 (2)	15
Visible-IR spectrometer	11 (25)	0.027 (1)	10
Cine-camera	4.5 (10)	0.054 (2)	100
Sub-Satellite or Articulated Boom			
Mass spectrometer	6.81 (15)	0.014 (0.5)	50
Electron probe	2.25 (5)	0.027 (1)	10
Electrometer	2.25 (5)	0.027 (1)	5
Temperature probe	0.9 (2)	0.014 (0.5)	2
Telemeter pkg.	4.5 (10)	0.027 (1)	70

Coordination of ground and space observations of chemical releases will be performed by mission control.

4.4.6.5 Potential Role of Man. Man will calibrate and operate the experiment instrumentation, deploy canisters, control the sub-satellite or deployment boom during the experiment while observing its position with respect to the released cloud, and monitor data obtained during the experiment. The scientist-astronaut will aid in experiment planning, and in coordinating simultaneous space and ground observations of releases. He will visually monitor releases, direct the experimental observations and determine experiment duration on the basis of these observations.

4.4.6.6 Available Background Data

a. A. D. Davilov, Chemistry of the Ionosphere, Plenum Press, (1970).

b. S. L. Valley, Handbook of Geophysics and Space Environments, McGraw/Hill (1966).

4.4.7 HEAT TRANSFER IN A CONVECTIONLESS MEDIUM

4.4.7.1 Objective. The objective of this experiment area is to obtain basic fluid heat transfer data under conditions where fluid convection due to gravity is essentially negligible. Data on temperature distribution and bubble and droplet formation will be obtained for both heating and cooling.

The experiment described in the following sections should be considered representative of more meaningful experiments which will eventually evolve and will require the use of similar experiment apparatus and impose similar crew and subsystem support requirements.

4.4.7.2 Description. The overall test system is shown in Figure 4-4. Boiling, bubble formation, and temperature stratification testing is shown in Detail A of Figure 4-4 and condensing and vaporization testing is depicted in Detail B. It is proposed to use two different fluids and several heater and condensing/evaporation surfaces for the total series of tests. Approximately ten tests are proposed for each test container. An estimate of the test durations is presented in Table 4-5.

Testing will include the determination of bubble growth rates, interaction of growing bubbles, hydrodynamic stability of bubble columns and nucleation processes. This data will be obtained visually using shadowgraph and direct image photography. Thermal layers and stratification will also be measured, primarily with thermocouples

Table 4-5. Test Durations.

Operation	Time of Operation (hours)	Number of Operations	Total Time (hours)
Boiling and Bubble Formation			
Inflight Set-up	4	10	40
Checkout	3	10	30
Standby	1/2	10	5
Experimentation	1	10	10
Condensing and Vaporization			
Inflight Set-up	4	10	40
Checkout	3	10	30
Standby	1/2	10	5
Experimentation	1	10	10
	Total Time (Hours)		170

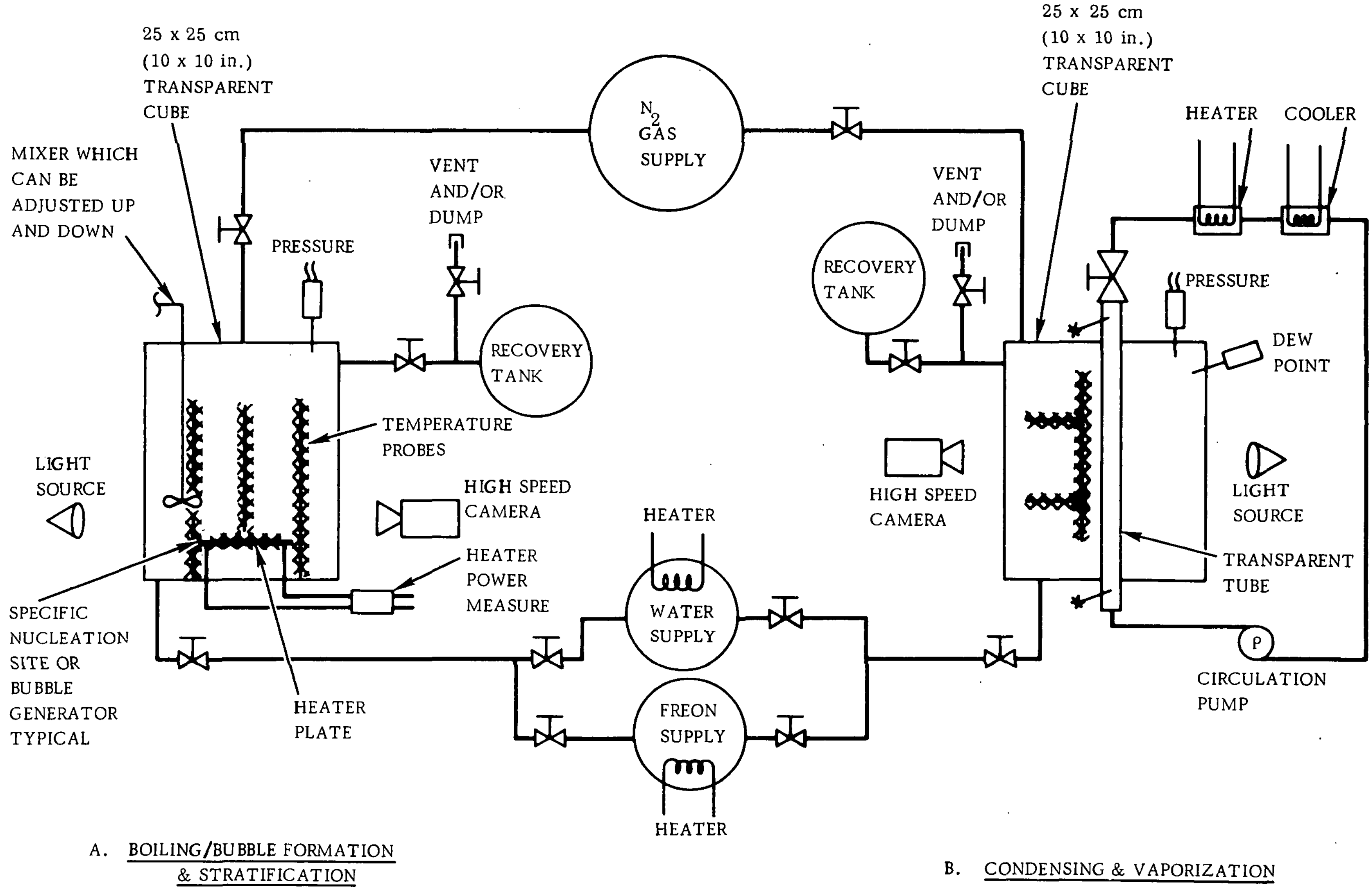


Figure 4-4. Heat Transfer Test Schematic

distributed throughout the fluid. Data will be gathered under both mixing and non-mixing conditions. Temperature measurements on the heater plate and measurements of heater power will provide additional data needed to define boiling curves for various test conditions.

In the case of condensation, the basic droplet nucleation process will be studied under various temperature and pressure conditions. Also, the degree of superheat and supercooling which can occur at low-g will be determined from temperature and pressure measurements.

4.4.7.3 Observation/Measurement Program. A list of instrumentation is presented in Table 4-6. Primarily visual data will be used to study bubble and droplet formation and interaction phenomenon. Pressure and temperature data are also obtained to determine stratification and the overall fluid state.

4.4.7.4 Interface, Support and Performance Requirements. Estimated weights of the various test hardware and test fluids, including storage and mounting requirements, are presented in Table 4-7. Power requirements are presented in Table 4-8. The peak power values represent the maximum power which will be used at any one time. The environmental acceleration must be less than 10^{-4}g's for all the proposed testing.

Table 4-6. Instrumentation Requirements

Item	Type	Quantity
Temperature Probes	Thermocouples ±0.36K (0.2f)	50
Pressure Transducers	Absolute	2
Dew Point Indicator		1
Power Measurement		1
Camera	Up to 8000 frames per Second (Average 200 frames per Second)	1
Shadowgraph Lenses		2
Film		12,000 m (40,000 ft)

Table 4-7. Weights and Volumes

Item	Weight kg	(lb)	Volume m^3	(ft^3)
Boiling Test Tank (including internal hardware and instrumentation)	9	(20)	0.028	(1.0)
Condensing Test Tank (including internal hardware & instrumentation)	9	(20)	0.028	(1.0)
Camera & Light Source	5	(10)	0.0028	(0.1)
Circulation Pump	2.2	(5)	0.0028	(0.1)
Condensing/Vaporization Cooler/ Heater Package	5	(10)	0.0056	(0.2)
N_2 Gas Supply	6.8	(15)	0.014	(0.5)
Water Supply	32	(70)	0.028	(1.0)
Freon Supply	45	(100)	0.028	(1.0)
Total	115	(250)	0.14	(4.9)

Table 4-8. Power Requirements

Item	Peak Power, W	Total Operation Time, hours
Boiling Heater	500	10
High Speed Camera	500	30
Light Source	100	30
Circulation Pump	10	15
Vaporization Heater	500	10
Condensing Cooler	500	10
Instrumentation	5	30
Supply Heaters	500	10
Total	2615 Maximum	145

The temperatures, pressures and power measurements will be acquired by the spacecraft data acquisition system. It is assumed that a measurement data rate of 100 samples per second will be required to about 0.05% accuracy. The data rate for 54 measurements is 65 k bits/second, assuming a 12-bit data word. Based on an 80-hour checkout and experimentation time (see Table 4-5) the total data acquired is 18.7×10^9 bits. Total energy required is 138 GJ (38.3 kW-hr).

4.4.7.5 Potential Role of Man. It is estimated that astronaut participation will be required essentially throughout the total experiment. This would be at approximately a one-man level. Duties would include set up of light and camera equipment and instrumentation and fluid quantity checkout. The astronaut will also determine the operating points of the experiment and decide when photographic and thermodynamic data should be gathered.

4.4.7.6 Available Background Data. A complete knowledge of boiling and condensing heat transfer mechanisms is lacking at the present time. One of the problems in obtaining basic data is that gravity induced convection currents are present at one-g which tend to disturb and influence the formation of bubbles and droplets. Low-g testing where significant convection can be eliminated is therefore desirable. Such testing was originally proposed with respect to the AAP program and identified as experiment numbers 0603A "Pool Boiling in Long-Term Zero "g" Environment" and 0603B "Nucleate Condensation of Fluids in Zero-Gravity."

Additional background data is available in the following publications:

a. Robert Siegel, "Reduced Gravity Heat Transfer", Advances in Heat Transfer, 1967.

b. "Gravity-Sensitivity Assessment Criteria Study", Convair Division of General Dynamics Corporation, NASA CR-66945, June 1970.

4.4.8 CRITICAL POINT PHENOMENA

4.4.8.1 Objectives. The objectives of this experiment are to obtain:

a. Quantitative information about the dependence of density upon pressure and temperature in the critical region of a single component fluid system

b. Quantitative information about the dependence of the adiabatic compressibility upon density and temperature in this same region

c. Thermal conductivity data of the fluid in this same region.

This data will be used to explore the credibility of certain existing theoretical conjectures about the unusual behavior of fluids near critical states.

4.4.8.2 Description. The basic experimental apparatus consists of a small fluid chamber with a one-liter volume, with very precise instrumentation for temperature control and measurement, precision pressure instrumentation, optical windows for viewing the fluid, and a mechanical device for changing and measuring the chamber volume. A sketch of the apparatus is shown in Figure 4-5.

The test cell will also incorporate a cylindrical acoustic cavity of several cubic centimeters. Sound speed will be measured by recording the resonant frequencies of the cavity as a function of pressure and temperature. The resonance will be excited and detected with a pair of piezoelectric transducers. The acoustic cavity and excitation and measurement equipment are schematically shown in Figure 4-6. A feedback system is used which will track with the resonance frequency at the cavity.

The working fluid will be xenon, although SF_6 and CO_2 could be used, of a specified and constant mass.

The experimental technique for the density measurements consists of establishing temperature control at a predetermined level, changing the volume in small steps, and measuring the pressure, volume and temperature after equilibrium has been established. Since the mass of xenon in the test chamber will remain constant, the density can be determined directly from the volume settings.

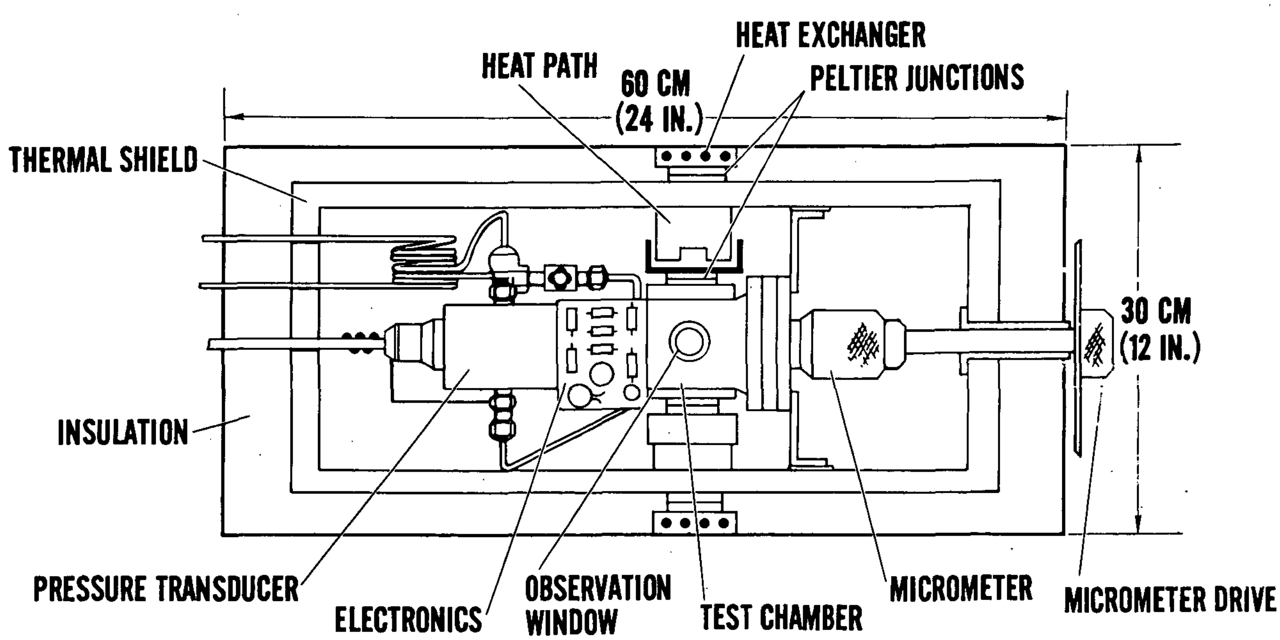


Figure 4-5. Critical State Experiment

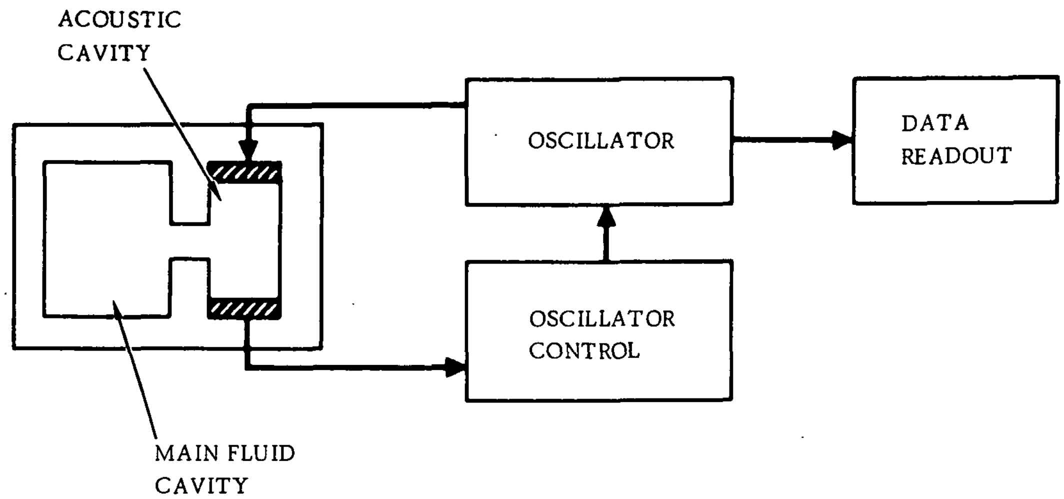


Figure 4-6. Acoustic Measurement Schematic

In addition to the density measurements described above, a test of the Lorentz-Lorenz relationship will be made. This requires the measurement of the refractive index of the fluid while at or near the critical point. The refractive index is related to the density as described in the background data. The apparatus required to accomplish this measurement is a narrow, collimated light beam and a photodetector system mounted so as to provide an angular read-out of the changes in the refraction of the light beam as the experiment is conducted.

A direct comparison between the two independent means of determining density can then be made.

Thermal conductivity will be determined by a transient technique which eliminates the necessity of directly determining the heat flux and also the requirement for using guard heaters and insulation to isolate the measurement. This will be accomplished by placing either a metallic sphere or cylinder inside a spherical or cylindrical test cavity such that the fluid will provide a thin shell around the metallic core. It is essential that the specific heat and mass of the core is known accurately and that an accurate temperature-difference measurement between the inner mass and the adjacent chamber wall can be made.

4.4.8.3 Observation/Measurement Program. At each temperature-pressure-volume point, the measurement program will record temperature, pressure, volume, light refraction and acoustic resonance frequency to determine density, thermal conductivity, and adiabatic compressibility.

Photographs of the fluid will be taken after equilibrium conditions are established. Data is required along six isotherms with each isotherm generated by approximately twelve points. Hence, seventy-two measurements are required. The astronaut must visually observe the fluid to denote the disappearance of one of the two phases to ensure that the measurements represent true equilibrium conditions at the critical state. Data recording will be automated.

Temperature control within the test apparatus must be established within a tolerance of 0.0011°K (0.002°F). An active control system employing reversible thermoelectric Peltier junctions will be employed. The thermal conductivity tests require a controlled and accurate temperature step of 0.55°K (0.1°F). Pressure within the test chamber will be around 5.5 to 6 mN/m^2 (800 to 900 psi), so safety precautions must be observed.

Each data point will take about one hour, thus the density and acoustic velocity tests will require about 100 hours. Another 100 hours will be required for the thermal conductivity measurements.

4.4.8.4 Interface, Support and Performance Requirements. The experiment will occupy a total volume of about 0.056 m^3 (2 ft^3) and be self-contained with the exception of electrical power and data readout and recording instrumentation. The experiment will weigh approximately 60 kg (130 lb). Electrical input power requirements are about 250 W. The total energy requirement, assuming a total test period of 200 hours, is 0.18 GJ (50 kW-hr). The data sampling rate is assumed to be 50 samples per second from each of 12 channels and the required analog accuracy will demand a 12-bit binary word. The total data rate is then 7.2 k bits/second. The total data requirement for the experiment is 5×10^9 bits. Still camera film requirements are assumed to be 250 pictures for a film weight of about 2.7 kg (5 lb).

The experiment apparatus will be designed to operate in 1 atmosphere over a 288 to 298°K (65 to 75°F) temperature range. Acceleration levels during the tests must be limited to 10^{-4} g. There are no other operational constraints.

4.4.8.5 Potential Role of Man. The astronaut will be required to select the temperature setting, determine that the system is functioning properly, and manually adjust the volume setting. He will monitor pressure and temperature to determine if the system has reached equilibrium and observe fluid visually to note two-phase or opalescent phenomena. After equilibrium has been reached, the astronaut will take a photograph, initiate the data logging cycle, and then establish conditions for a new data point.

4.4.8.6 Available Background Data. Consider a pure substance in an apparatus in which the temperature, pressure and volume can be regulated and measured. We may then consider the special properties of the critical point (T_c). Above T_c there is no boundary between the vapor and liquid. Below T_c the two phases coexist and discontinuities occur in physical properties during the transition. The isothermal compressibility,

$$K_T = - \left(\frac{1}{V} \frac{\partial V}{\partial P} \right)_T$$

becomes very large at T_c and V_c, and it is in this region that the effect of gravity becomes significant. When the compressibility becomes very large, gravity will create a significant density gradient in any finite sized sample. This means that in a terrestrial experiment, the conditions of the experiments described in the apparatus of Figure 4-5 can never be achieved. It is impossible to regulate the density in a microscopic measurement and the sample size places a limit on the ability to approach true critical behavior.

The existence of these gravity-induced density gradients suggests a useful avenue of experimentation in a zero-gravity environment:

In a terrestrial experiment, the density, ρ, cannot be determined by a direct macroscopic measurement in the vicinity of the critical point. Indirect localized means, therefore, must be employed to gauge the density in a narrow horizontal layer of fluid. The procedure used measures the refractive index, n, with a narrow light beam and relate it to the density by the Lorentz-Lorenz (LL) relation,

$$\frac{4\pi}{3} \rho\alpha = \frac{n^2 - 1}{n^2 + 2}$$

where α is the polarizability. The LL relation is strictly true only in a medium in which density fluctuations are of a much shorter wave-length than the light. At the critical point, however, the density fluctuations become of the same magnitude as the wave-length of light (the origin of critical opalescence) and the validity of the LL relation is open to question.

Since the LL relation is the basis of all accurate measurements of vapor-liquid critical point phenomena, it seems desirable that a zero-gravity environment be used to test its validity. This could be done by measuring the density by the refractive index method and simultaneously exploiting the absence of any gravity-induced density gradients to make an independent direct measurement of the density near the critical density. This experiment would either confirm the validity of terrestrial measurements or provide data upon which a theory to correct the LL relation for density fluctuations could be based.

References

a. K. Fritsch and E. F. Carome, "Behavior of Fluids in the Vicinity of the Critical Point", John Carroll University, NASA CR-1670, September 1970.

b. Critical Phenomena, Proceedings of a Conference held in Washington, D.C., M. S. Green and J. V. Sengers, eds., National Bureau of Standards Miscellaneous Publication 273, U.S. Government Printing Office, Washington, D.C., issued December 1, 1966.

c. P. Heller (1967), Rep. Prog. Phys. 30, 747.

d. B. L. Smith (1969), Contemp. Phys. 10, 321.

e. "Study of Liquid Drop Dynamics in Zero Gravity," EOS Report 7171-Final, November 1967, K. Kmapp and H. Niser, Electro-Optical Systems, Inc., NASA Contract NAS8-21012.

4.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

The summary data presented in Table 4-9 represents, in the best judgment of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

Table 4-9. FPE Summary Interface, Support, and Performance Requirements

Mass (Includes support equipment)	2700 kg (6200 lb)
Volume (Includes support equipment)	10 m^3 (350 ft^3)
Power	3.2 kW
Crew Skills	Physicist Thermodynamicist Physical Chemist Electro-Mech. Tech.
Data Rate	2.4 Mbits/sec
Logistics Up (Per 30 Days)	85 kg (190 lb)
Logistics Down (Per 30 Days)	85 kg (190 lb)
Pointing & Stability	±0.017 rad (±1 deg)
Orbit Alt. & Inclination	Any consistent with vacuum and g-level requirements.
Unique Environment Requirements (G-level constraints)	10^{-3}g max. (At interface between facility structure and g-isolator bench.)

4.6 POTENTIAL MODE OF OPERATION

The following modes of operation shall be considered for this FPE:

Mode A Limited on orbit stay time as with Space Shuttle sortie missions.

Mode B Extended on orbit stay-time revisited periodically by a Shuttle

Mode C Extended on orbit stay-time as with Space Station missions. The laboratory could be an integral part of the station, or could be within a separable module which is docked to the station.

Modes A and C are both applicable for the representative experiments described herein. Mode B does not appear practical due to the heavy involvement of man.

4.7 ROLE OF MAN

This FPE requires man as an active experimenter. He will set up, conduct, and evaluate experiments in a role similar to the role he plays in an Earth-based laboratory. Many of the experiments require a trained physicist or physical chemist in at least the initial experimental observations due to the large degree of uncertainty regarding the outcome of the experiments.

Although the majority of the measurements made will be logged by the onboard data acquisition system for permanent experimental storage and for displays to the experimenter, the control of the experiment and selection of data collection methods will be under control of the experimenter.

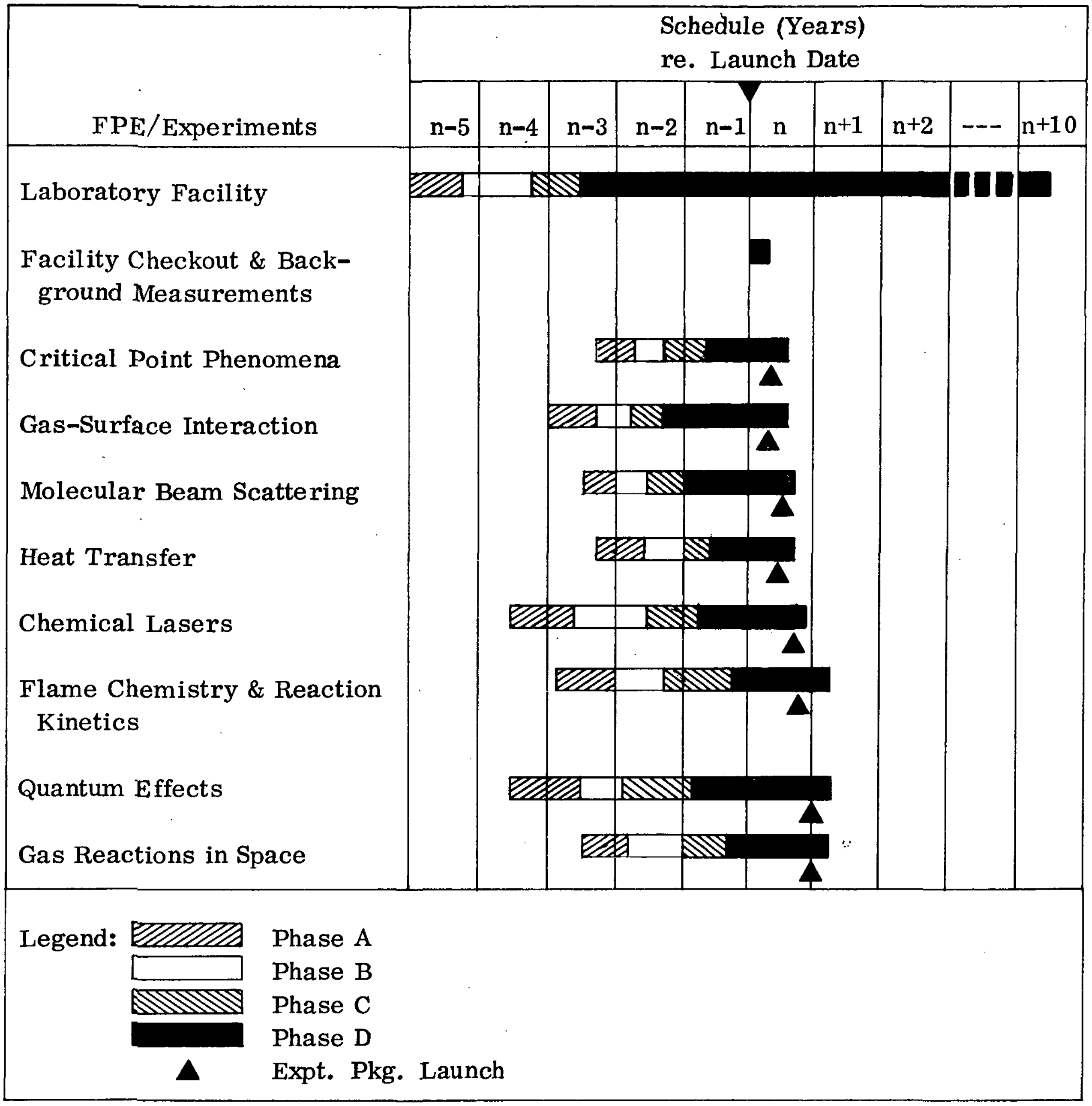
4.8 SCHEDULES

Table 4-10 illustrates the development and flight schedule for this FPE. The sequence of experiment package development and flight shown in this table is typical and is only one of many possible combinations. No attempt has been made to assign relative values or priorities to these experiments.

4.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

Some prelaunch activities and GSE will be required to service high-vacuum instrumentation and equipment which uses cryogenics, such as the superconducting magnet. The magnet will be cooled to operating temperature prior to launch, and maintained cold thereafter. Instruments which cannot be operated at pressures above 13 mN/m^2 (10^{-4} torr) will require that vacuum systems be available for prelaunch checkout.

Table 4-10. FPE Development and Flight Schedule



4.10 SAFETY

4.10.1 FIRE SAFETY. Some of the experiments require controlled combustion as an integral part of the experiment (4.4.3 and 4.4.4). A fire safety analysis must be made of these experiments and potentially hazardous conditions protected against. In case of an accidental, uncontrolled fire, the fire detection and control system must be capable of dealing with this emergency.

These problems and their potential solutions are discussed at some length in Section 4.4.12.

4.10.2 WASTE DISPOSAL. The disposal of liquids, solids and gases from the candidate experiments as well as other chemical agents used in the laboratory present a potential problem. In addition to the fire hazard potential in these various agents, there is the possibility of injurious vapors being released from the accidental mixing of two or more agents.

Because of the possibility of external surface contamination of the spacecraft, venting of these products to the space vacuum will have to be carefully considered.

4.11 AVAILABLE BACKGROUND DATA

Background data pertaining to individual experiments is listed within each experiment description, where available.

A discussion of the philosophy behind the purposes and utilization of such a laboratory facility is contained in NASA CR-61296, Starlab Final Report, August 1969.