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SPACE PROCESSING APPLICATIONS PAYLOAD EQUIPMENT STUDY

VOL. I. EXECUTIVE SUMMARY

DPD NO. 406
DR NO. MA-04
DCN NO. 1-3-21-00235
CONTRACT NO. NAS 8-28938

AUGUST 1974

R. L. HAMMEL

PREPARED FOR

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

BY

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FOREWORD

Phase II documentation prepared for the Requirements and Concepts for Space Processing Payload Equipment Study under Contract NAS 8-28938 resulted in a three-volume report. These volumes are as follows:

Volume I.		Executive Summary
Volume II.		Technical
	IIA.	Experiment Requirements
	IIB.	Payload Interface Analysis
	IIC.	Data Acquisition and Process Control
	IID.	SPA Kit
	IIE.	Commercial Equipment Utility
Volume III.		Programmatics and Payload Accommodation

Volume II, Technical, is published as five sub-volumes in order to facilitate presentation of topical groupings of data.

Phase I documentation was previously documented in 1973 as three volumes under the title, Requirements and Concepts for Materials Science and Manufacturing in Space.

One feature of this study has been the close association between the NASA Shuttle Sortie Working Group on Materials Science and Manufacturing in Space and the study contractor, TRW Systems Group. The NASA-MSFC study COR, Mr. Kenneth R. Taylor, has provided TRW Systems Group with working group documentation and, in turn, has coordinated study task results into the activities of the working group.

Volume I is based upon a paper presented at the Third Space Processing Symposium 1974 at NASA-MSFC. The authors contributing to Volume I are listed below:

K. R. Taylor - NASA/MSFC
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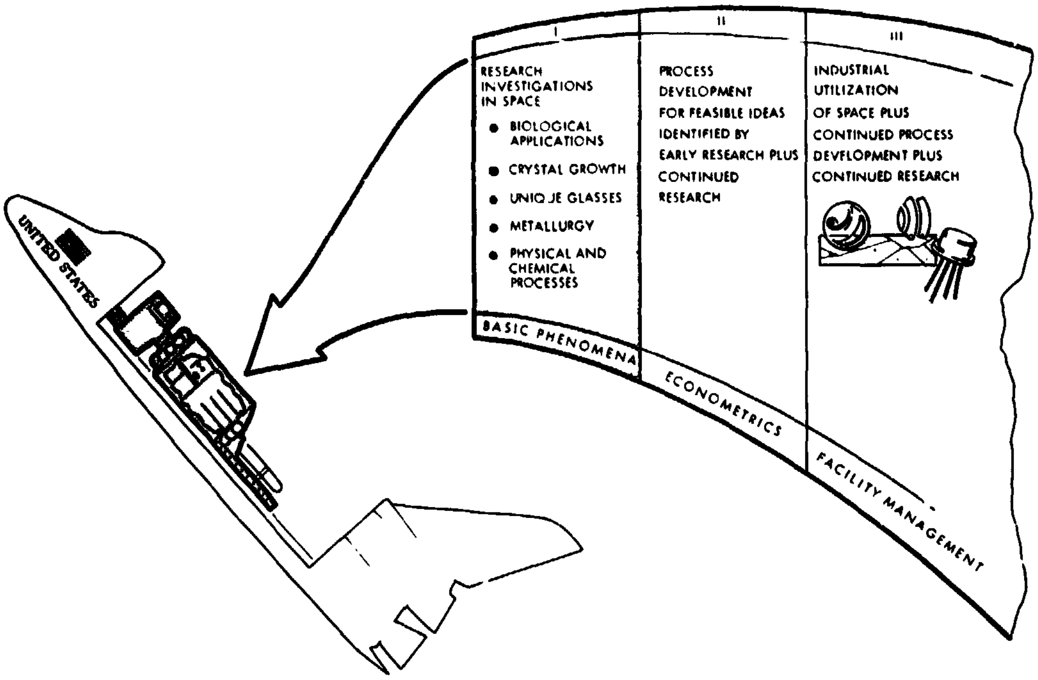

SUMMARY

This Executive Summary presents results and concepts derived during the conduct of a 24-month study performed for NASA's George C. Marshall Space Flight Center under contract NAS 8-28938 by TRW Systems Group. The prime objective was to derive and collect payload information so that anticipated Space Processing Payload requirements were noted in the Spacelab and Orbitor planning activities.

INTRODUCTION

NASA's Space Processing Program [1] has generated six objectives and their related phases for the 1980-1990 time period, as shown in Table I. In total, the objectives encompass the required course of product research and development from the initiation of SPA Shuttle/Spacelab operations to the end-item goal of engaging in commercial manufacturing operations in earth orbit.

This study has addressed concepts and requirements for Space Processing payloads to accommodate the performance of the Shuttle-supported research phase. Since the purpose of the early activity is to identify those processes and materials having technical merits warranting exploitation, ample opportunities to examine many candiates will be needed. The product(s) and associated payloads(s) for prototype or manufacturing activities will be identifiable only after successful accomplishment of the initial R&D efforts.

Consistent with the performance of a research program, frequent short-term, sortie-mission modes are especially suited [2] to verifying space processing hardware performance and refining experiment protocols. Furthermore, return of space processed samples to earth represents a fundamental difference between this discipline and remote, sensor-type missions such as earth observations or astronomy.

While perhaps not so obvious, an equally important feature will be the routine retrieval of the payload equipment via Shuttle. This will open a new era of testing in which reuse, reconfiguration and modifications of the payloads can systematically occur. This latter feature dictates the use of a reusable, reconfigurable, payload design and portends a modular approach to payload design and integration.

Table I. SPA Objectives and Their Related Time Phasing

Objectives	Program Phases
1. Make space easily accessible to the international scientific and industrial community for research and development work in materials science and technology. 2. Develop techniques that take full advantage of the characteristics of space flight to achieve experimental and process conditions that are not obtainable at competitive costs on earth.	<u>Initiation Phase</u> (Manned Missions--Apollo, Skylab, ASTP—in the 1970's and start of Spacelab flights in early 1980's)
3. Employ the novel materials research and development techniques that are possible in space to acquire new knowledge in technologically important areas of materials science and technology. 4. Apply R&D results obtained in space to advance materials technology generally and, in particular, to invent processes to manufacture products in space for use on earth.	<u>Research and Development Phase</u> (Early to mid-1980's)
5. When appropriate, reduce selected space manufacturing processes to practice and conduct pilot production operations to demonstrate their practicality.	<u>Reduction to Practice Phase</u> (Mid to late 1980's)
6. When capabilities to manufacture economically viable products are achieved, initiate commercial production operations in space.	<u>Commercial Production Phase</u> (1990 and beyond)

It is believed that the practice of learning how to conduct space processing activities using multi-purpose, reusable and reconfigurable payloads aboard Shuttle will be an active process. This learning process must be aided by establishing simplified hardware/host vehicle and operational interfaces. Design approaches must be fostered that will allow the scientists to have rapid, convenient and repeated access to Space Shuttle facilities in a cost effective manner.

SALIENT REQUIREMENTS ANTICIPATED

Keeping in mind that the ultimate objective of Space Processing is the achievement of product commercialization, the following anticipated requirements[3] describe the nature of the payload equipment capabilities that are necessary to engage in a Shuttle-implemented, R&D phase.

o <u>*Wide Ranging - Broad Experimental Activities*</u>

The benefits of performing materials processing experiments under a near-weightless condition in space is projected to have applicability to numerous and various types of materials. These range from electronic materials, crystals and glasses, metals, alloys and compounds to biological specimens. While specific product-oriented activities are yet to be established, initial investigations have uncovered potential space processing in the following areas: crystal growth, purification/separation, mixing, solidification, and chemical and physical processes in fluids.

- *Evolutionary, Ongoing R&D Efforts*

  An initial period spanning many years will be necessary to establish and conduct an ongoing research and development program which will lead to the ultimate discipline goals of identifying and implementing the production of economically viable space products. The in-space R&D efforts will be highly evolutionary, building heavily upon an experimental learning process as the technical community determines methods and evaluates results through the aggressive performance of an in-space R&D program.

- *Process Development Emphasis*

  Due to a lack of prior art, much of the experimental activities will necessarily involve emphasis on identifying and characterizing those process methods and controls which are necessary in the use of the payload equipment.

- *Identification of Sufficient Equipment Capability To Engage the Interest of the Technical Community*

  To best serve the space processing community, provisions must be made for providing an inventory of equipment which is responsive to its R&D needs and which can readily be configured into research payloads. Fortunately, many experimental areas in materials science and technology have common equipment requirements, therefore, the laboratory approach which provides a complement of apparatus and instruments appears feasible. This approach would serve a large number of potential investigators, yet would maintain economical equipment and apparatus development costs. A rational, initial inventory of equipment must be established and must be updated as the program develops in order to meet the wide spectrum of potential research needs.

- *Identification of Equipment Required for Projected Space Processing R&D Endeavors and Matching Host Vehicle Capability*

  As stated in the introduction, perhaps the greatest challenges facing both the Space Shuttle and Spacelab development are those concerned with system usage, not with the vehicles themselves. A new era is beginning, the era of space exploration which requires participation by a very broad cross section of the scientific community. The emphasis is no longer upon simply overcoming phenomena due to a weightless environment but upon exploiting and using these phenomena to achieve economic benefits. In the exploitation phase, the problem is to take advantage of the physical and chemical changes caused by the in-space environment. To achieve such results, the payload design engineer and the research scientist will have to work closely together so that requirements are continually matched with capabilities and vice versa.

Workable SPA system level concepts must be based on:

- o real requirements
- o simplified operational procedures
- o minimum interfaces with the flight vehicle

The participation of the international scientific community is vital to the establishment of this system. Only in this way can the design of space processing payloads provide rapid, convenient and repeated access to space in a cost-effective manner.

A review of six R&D categories (as listed below) was conducted using exemplary experimental activities in each R&D area to establish the following:

- Experiment functional requirements
- Required types of apparatus and instruments

The Space Processing R&D categories considered include:

- Biological Processes
- Chemical Process in Fluids
- Crystal Growth
- Glass Preparation
- Metallurgical Processes
- Physical Processes in Fluids

In this process, over 40 separate experiment classes were reviewed. Each individual experiment class considered represents a potential area of study conceivably of interest to many principal investigators. The resulting equipment and instrumentation identified to support the experimental efforts exceeded 90 items. Both the number of exemplary experiment classes and required associated payload equipment reflect the wide ranging diversity of anticipated space processing activities.

o *Establishment of Capability of Accommodating Frequent, Repetitive Flight Opportunities*

The nature of contemplated space processing R&D studies will require frequent and repetitive flight opportunities by most investigators to satisfy their experimental objectives. For this reason planned research studies rather than single-point or random opportunities are needed.

A very active learning process will occur, particularly during the initial years. Thus, progress in Space Processing as a discipline will be closely paced by how repetitively the multitude of investigators can obtain a sufficient number of short-duration, fast-reaction flight opportunities. Shuttle-supported, 7- to 30-day-long, earth orbital, sortie missions afford an excellent means provided that the payload equipment configurations can match available resources. This is particularly necessary when considering shared payload opportunities. Furthermore, quick reaction alternatives must be possible, to allow a constant rematch of continuously evolving scientific requirements with ongoing flight opportunities.

CONCEPTS FOR MEETING ANTICIPATED REQUIREMENTS

The nature of the equipment concepts to meet the experimental needs and usage requirements for both the user and operator were considered. The establishment of an initial equipment inventory which would be made available to support multiple experimenters is a paramount issue to Space Processing. In addition to the samples, other minor experiment-unique hardware may occasionally be required by an individual investigator; but, primarily the payloads would be formed from a NASA inventory of equipment. Evolutionary changes in both the apparatus designs and equipment inventories would naturally occur as in-space experimentation progresses. The following paragraphs describe[3] activities or approaches directed toward planning ahead for the occurrence of the discussed concepts.

Identification of Experimental Apparatus Using a Laboratory Approach to Provide a Basic Inventory of Equipment Capable of Serving Multiple Experimenters

An initial inventory of equipment and instruments has been identified, based upon the examination of a cross section of experiment functional requirements. A listing of this inventory is included in the attachment. Equipment functional specifications were then prepared which describe the anticipated areas of usage, functional requirements/rationale and specifications or criteria. Thirty-six specifications were prepared which cover 55 items. These documents quantify the equipment and instrumentation and provide a reference baseline description for record keeping. This inventory of apparatus can then be formed into payload groupings to serve a host of experiments. Large, custom-made facilities must be avoided in order to remain flexible and versatile in the grouping concept.

Derivation of Equipment from Commercial Technologies to the Greatest Extent Possible

Examination of commercial equipment technologies revealed that the functional performance requirements of space processing equipment could generally be met by state-of-the-art design practices. Thus, an apparatus could be evolved from a standard item or derived by custom design using present technologies. About 15 percent of the equipment needed has no analogous commercial base of derivation and requires special development. This equipment is involved primarily with contactless heating and position control.

The derivation of payloads using commercial equipment sources provides a broad and potentially cost-effective base upon which to draw. Since the derivation of payload equipment from commercial technologies poses other issues beyond that of the identifiable functional performance, additional comment is provided in a later section; but preliminary results on selected equipment testing of outgassing characteristics performed by Beckman Instruments under Contract NAS 8-29776 appear quite favorable.

Modular Payload Equipment Groupings

Concepts for structurally grouping inter-related apparatus and instruments have been based upon modular approaches. On this basis, the following benefits occur:

- Payload equipment groupings can readily be assembled for a variety of possible mission opportunities ranging from austere to dedicated.
- Reconfiguration and refurbishment can be a practical, routine occurrence.
- It is possible to adapt to many possible host-vehicle, interface schemes.
- Equipment and apparatus interface management is effected prior to host vehicle integration.
- Standard interfaces can be defined and maintained between the payload equipment and the host vehicle.

Major payload equipment groupings have been organized around the following five payload subelements:

Furnace. A grouping of furnaces and associative apparatus for performing activities in which physical contact with the specimen is permissible.

Levitation: Apparatus providing contactless positioning and heating of specimens with associated process control and characterization.

Biological: Equipment which produces separation of biological samples with associated preservation and storage capacity.

General Purpose: Provides services with associated characterization equipment supporting the accommodation of a variety of modest temperature research - physical or chemical fluid studies.

Core: Consists of centralized data acquisition, processing and equipment control functions.

By example, the Furnace subelement equipment listing and interfaces are shown in Figures 1 and 2.

In all cases each of the first four individual experiment subelements, or portions thereof, would be capable of being used independently of other payload equipment when combined with the core subelement. Such autonomous groupings are particularly attractive for participation in shared payload opportunities and to accommodate shifts in functional emphasis.

The subelement concept further lends itself to identifying and establishing Spacelab accommodation modes and operational requirements. Engineering descriptions of these payload groupings have been prepared and are available in Reference 3. Study efforts also [illegible] self-contained automated payload concepts which would be [illegible] either with or without a Spacelab as part of a Shuttle payload complement.

Several internal payload accommodation modes were examined. Figure 3 shows accommodation alternatives using current Spacelab dimensions and either a SPA dual aisle or arch payload configuration. An artist's illustration of a dual-aisle payload is shown in Figure 4.

SPA power and heat rejection kit (PHRK) concepts which have been identified are shown in Figure 5. The SPA kit is visualized as an augmenting power and heat rejection capability when used in conjunction with Spacelab. By being capable of containing automated furnace and levitation equipment the kit also provides the payload basis for experimentation in an automated mission mode.

MISSION PLANNING

In the foregoing section, the requirements imposed on the payload design by both the space processing goals and the space shuttle flight system were discussed. This section will discuss the current Space Shuttle mission model and its implications on payload design.

FIGURE I. FURNACE SUBELEMENT ORGANIZATION OF EQUIPMENT

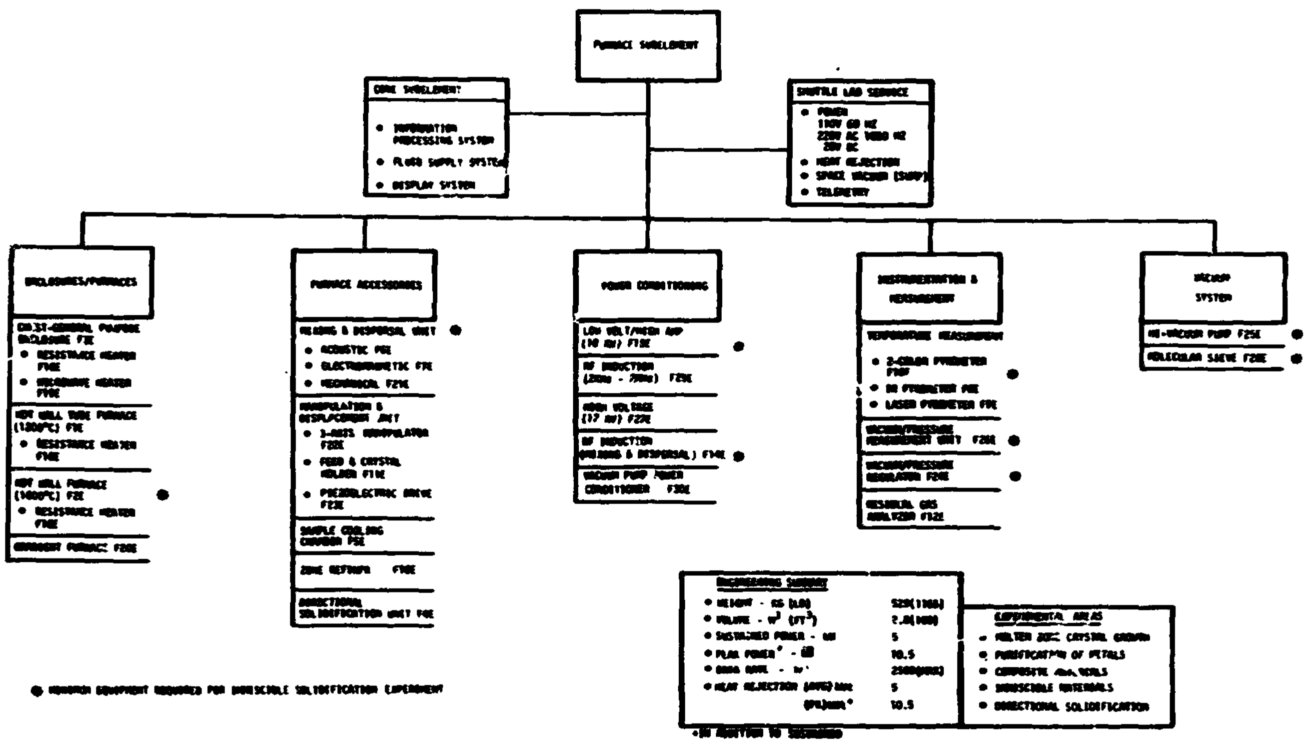

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FIGURE 2. FURNACE SUBELEMENT INTERFACES

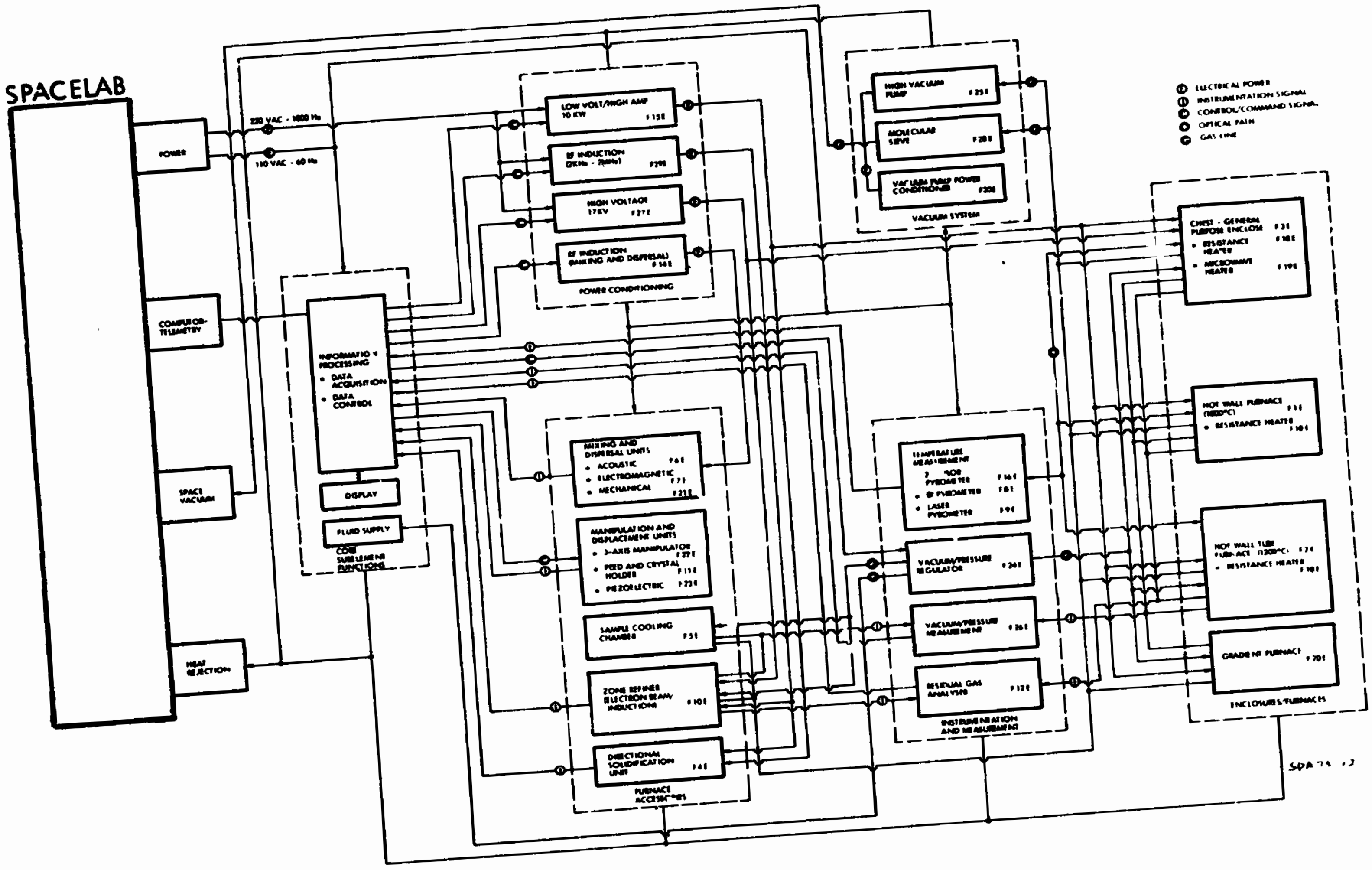

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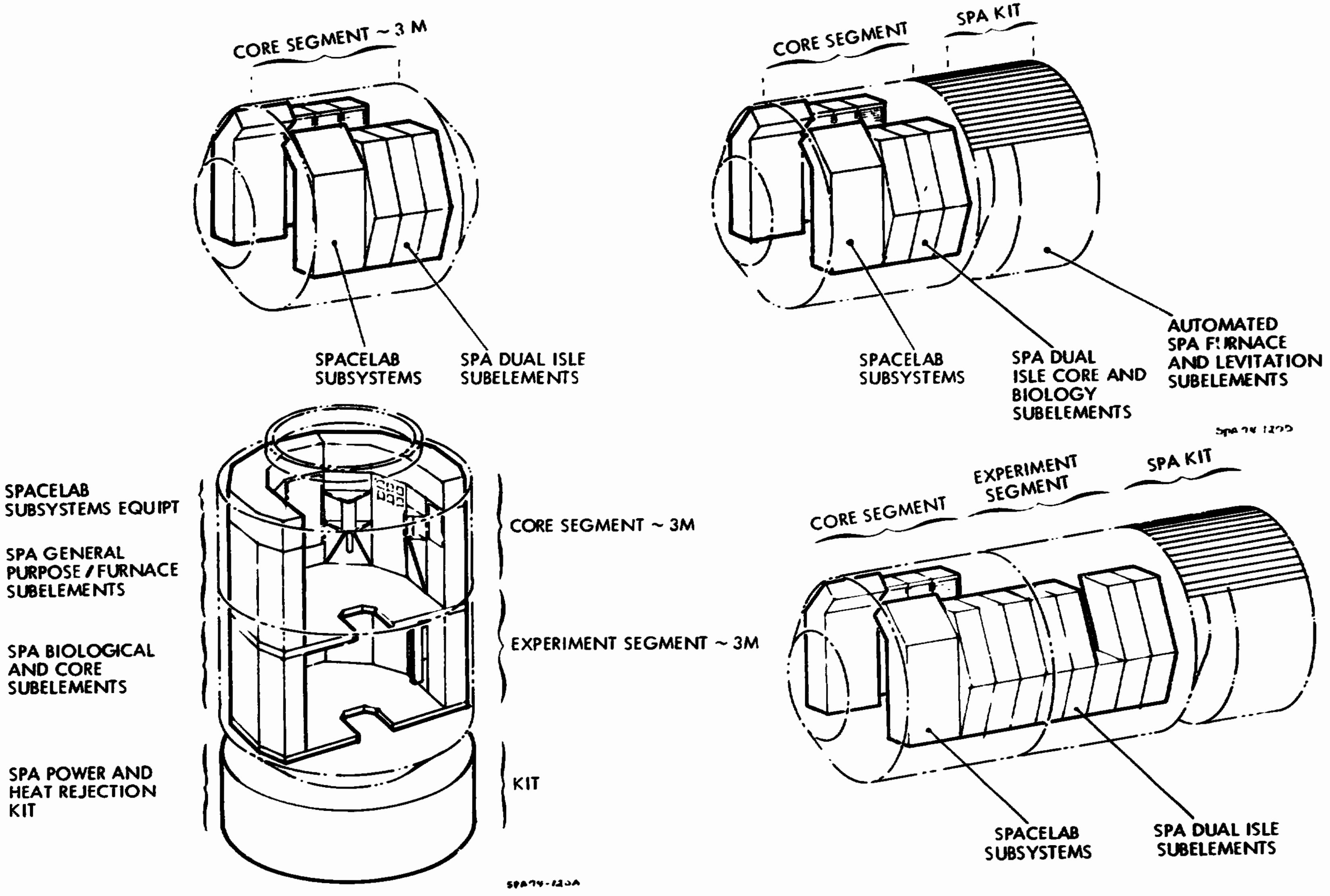
FIGURE 3. ACCOMMODATION MODES OF SPA PAYLOAD EQUIPMENT



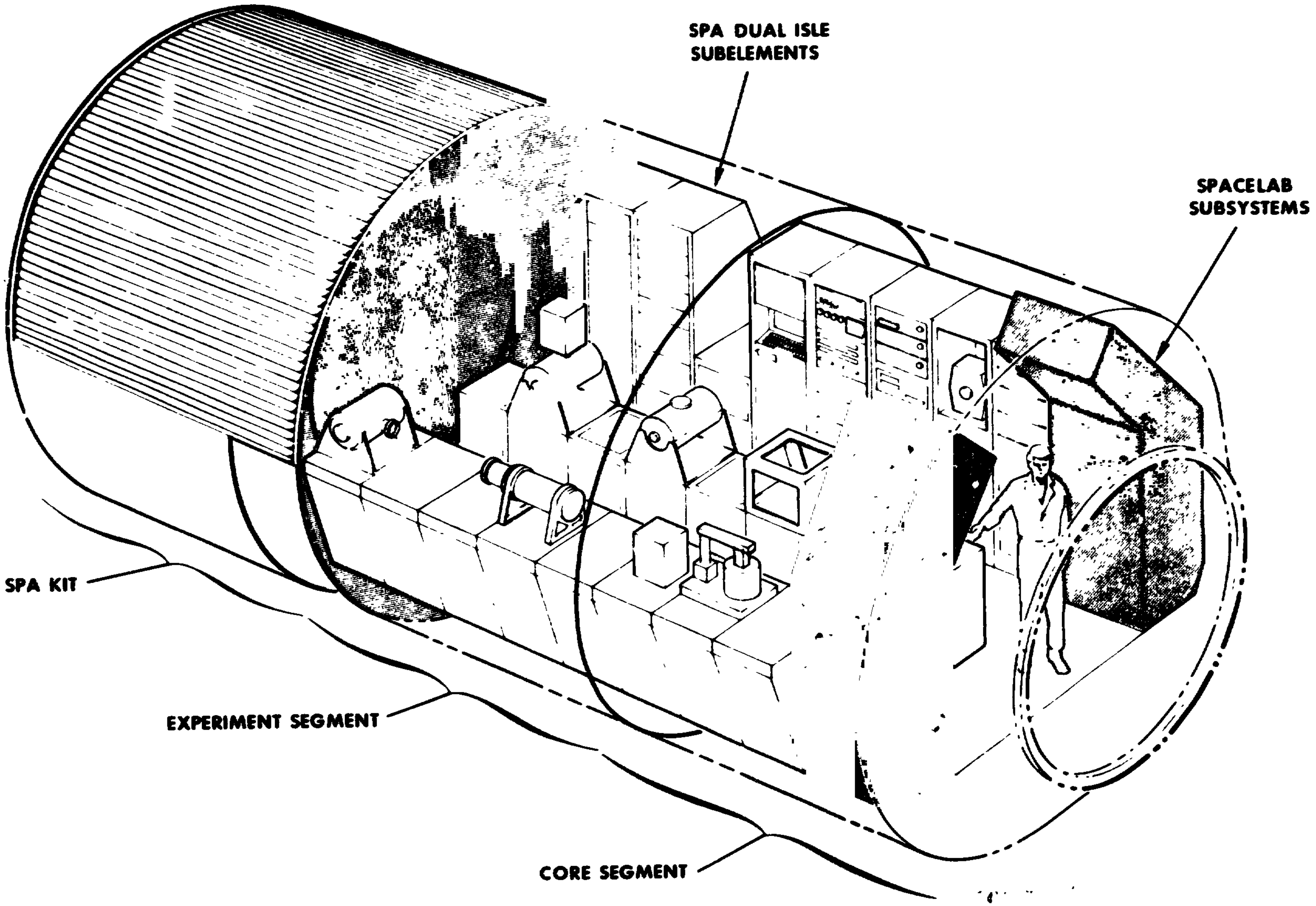
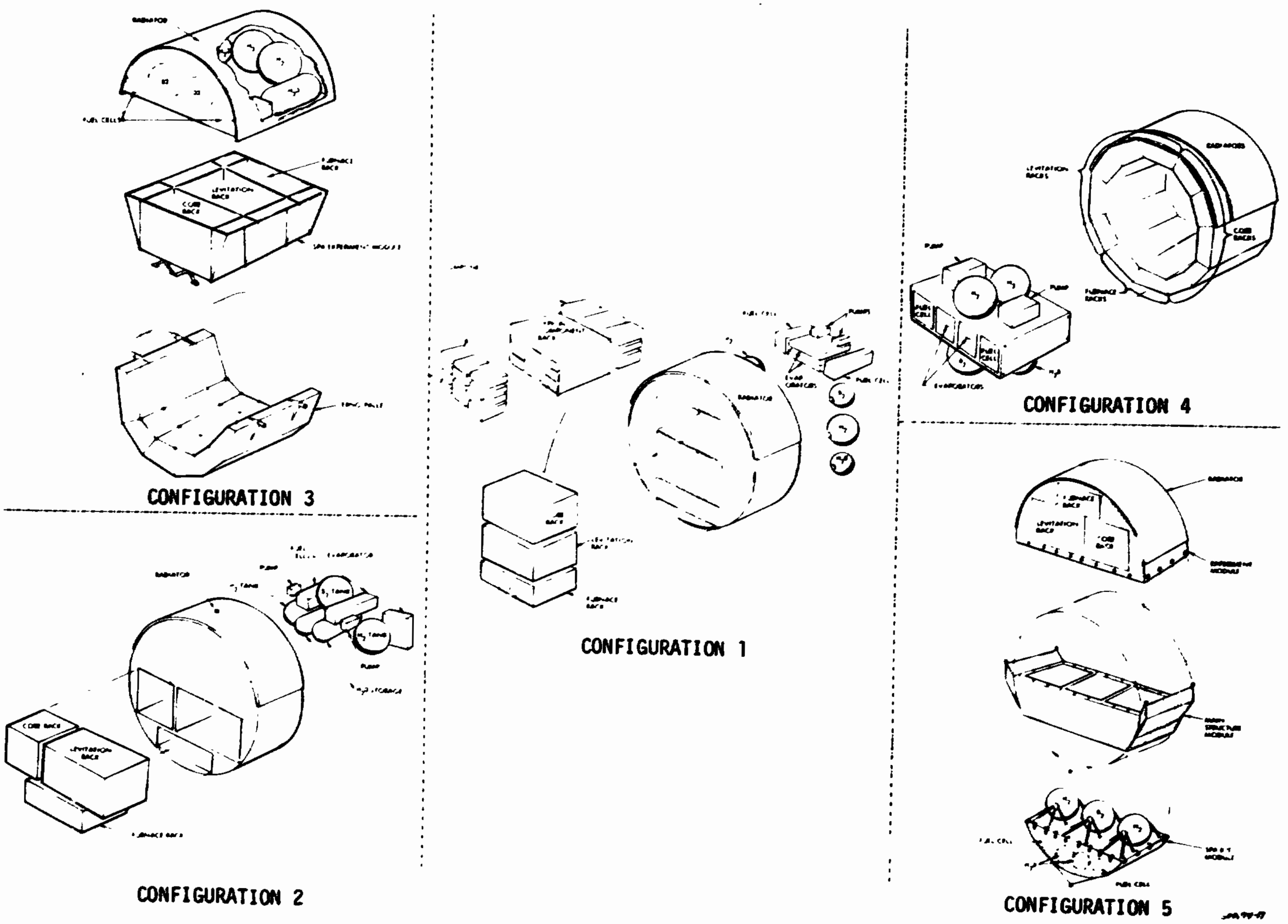


FIGURE 4. ARTIST'S RENDERING OF LONG LAB - TWO ISLE CONFIGURATION

FIGURE 5. CONFIGURATION CONCEPTS FOR SPA POWER/HEAT REJECTION KIT AND EXPERIMENT EQUIPMENT MODULE



Examination of the Space Shuttle System's mission traffic model provides a basis of identifying the degree to which frequent and repetitive access to space might occur for the purpose of conducting Space Processing activities. Furthermore, this enables the structuring of the complement of payload types that are required in order to effect the projected incorporations into the various Shuttle mission modes. Ultimately, the number of sets of payload equipment of each of the defined types can be derived in conjunction with other planning and scheduling constraints.

NASA Mission Model

The most recent mission model contains 727 flights over the period from 1980 to 1991. Currently, payloads are assigned to 488 of these flights and 239 remain unassigned. Figure 6 presents a division of flights by type: Dedicated, Assigned and other opportunities.

Space Processing Payload Flight Requirements

Space processing, both for reasons of operating economy and achieving program goals, must take advantage of every flight opportunity. In fact, an effective space processing experiment program will require a logical iterative sequence of flight experiments. A true evaluation of some processes may require a series of flight experiments in which one parameter at a time is varied. Considering this and the very large number of materials that must be evaluated, it appears that a space processing payload could be effectively utilized on nearly every flight.

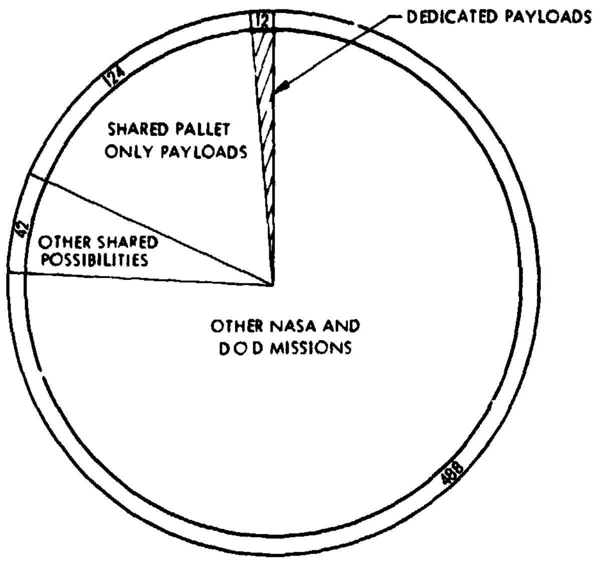
In light of the mission model and the desire to maximize the number of SPA flight opportunities, six Shuttle System accommodation mission mode types are summarized in Figure 7. Of the six modes listed, Spacelab-dedicated, Spacelab-shared and automated modes appear to represent the concepts that will require major anticipatory payload planning and will afford maximum SPA flight opportunities within the mission model.

To undertake this many flight opportunities and to utilize fully the Space Shuttle's payload capability will require an inventory of payloads designed to match the capacities and restrictions imposed by each type of mission. In order to accomplish the above objectives, an inventory of payload equipment has been defined which can be combined to form complements of payloads. Specific details are outlined in the following sections.

Equipment Inventory

An initial listing of equipment items was derived as a result of an analysis of generic classes of representative Space Processing experiments. Subsequently, review and updating of the equipment inventory has and is expected to be a continuing effort due to the development of the experimental areas within the international technical community. It is to be emphasized that a continuing active participation of the technical community with regard to the equipment functions will control the prolificacy of the experimental program to a great degree. Use of this preplanned complement of apparatus will occasionally be supplemented by individual, experiment-

FIGURE 6. SUMMARY OF PLANNED AND POTENTIAL SPA SPACE MISSIONS FROM 1980 THROUGH 1991

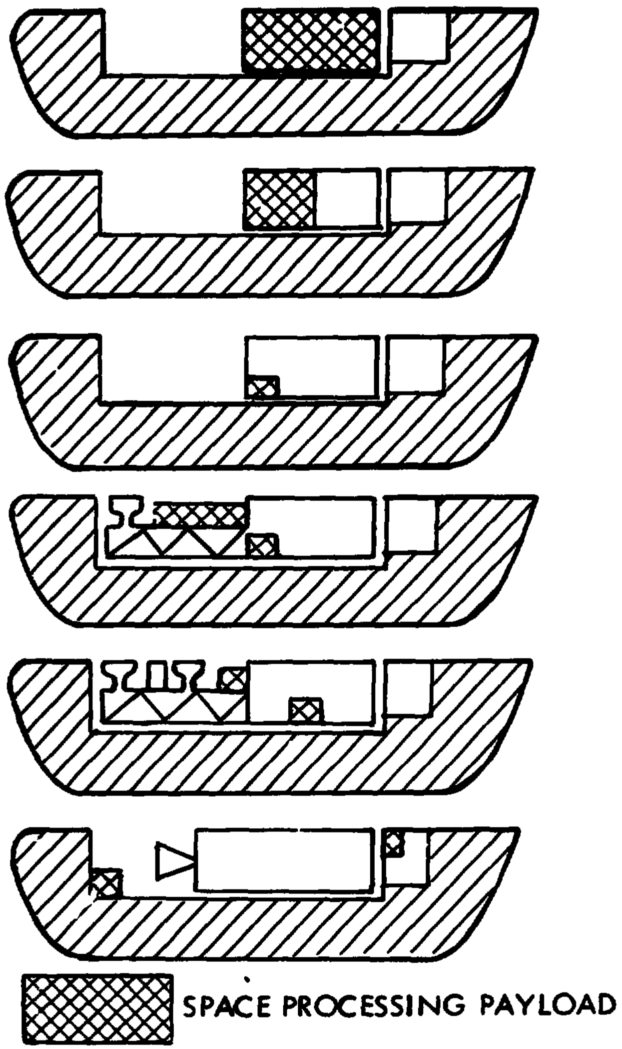


SPA PAYLOAD CATEGORY / CY	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL SPA PAYLOADS
SPA DEDICATED SPACELAB SORTIE FLIGHTS	1	1	1	1	1	1	1	1	1	1	1	1	12
SPA SHARED MISSIONS/PALLET ONLY FLIGHTS	0	4	12	12	12	12	12	12	12	12	12	12	124
TOTAL ASSIGNED SPA PAYLOADS ON SHUTTLE/SPACELAB FLIGHTS	1	5	13	13	13	13	13	13	13	13	13	13	136
SPACE AVAILABLE FLIGHTS WHERE SPA PAYLOADS COULD BE ACCOMMODATED*	2	6	0	2	7	7	2	7	3	1	3	2	42
TOTAL SPA PAYLOAD FLIGHT OPPORTUNITIES	3	11	13	15	20	20	15	20	16	14	16	15	178

CRITERIA FOR SELECTING "SPACE AVAILABLE FLIGHTS WHERE SPA PAYLOADS COULD BE ACCOMMODATED"

1) TEN FEET OF RUNNING LENGTH IS AVAILABLE IN SHUTTLE CARGO BAY.
2) SHUTTLE PAYLOAD UP WEIGHT DOES NOT PRESENTLY EXCEED 53,000 LBS.
3) SHUTTLE PAYLOAD LANDING WEIGHT DOES NOT PRESENTLY EXCEED 23,000 LBS.

FIGURE 7. POTENTIAL MISSION MODES FOR ACCOMMODATING SPACE PROCESSING PAYLOADS*



1. DEDICATED SPACELAB PAYLOAD
2. SHARED SPACELAB PAYLOAD
3. MINIMUM IMPACT CARRY-ON PAYLOAD (LIKE APOLLO FLYBACK)
4. SHARED AUTOMATED PAYLOAD ATTACHED TO PALLET WITH NECESSARY CONTROL AND DISPLAY EQUIPMENT IN SPACELAB OR SHUTTLE
5. MINIMUM IMPACT CARRY-ON AUTOMATED PAYLOAD ATTACHED TO PALLET WITH NECESSARY CONTROL AND DISPLAY EQUIPMENT IN SPACELAB OR SHUTTLE
6. MINIMUM IMPACT CARRY-ON AUTOMATED PAYLOAD LOCATED IN CARGO BAY WITH NECESSARY CONTROL AND DISPLAY EQUIPMENT IN SHUTTLE

*DELIVERY/RETRIEVAL OF AUTOMATED SATELLITES NOT INCLUDED

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unique fixtures supplied by the investigator to further enhance the equipment utility.

Equipment Functional Specifications

A summary of an inventory of equipment is presented in the attachment. Expanding upon the summary data of the attachment has been the preparation of Equipment Functional Specifications. The equipment functional specifications which have been drafted serve as a starting point in the quantification of the equipment and instrumentation. They provide both a reference baseline description and the basis for record keeping. The initial specification performance requirements, design approach and descriptions must be treated as tentative at this time and will require updating as further definition progresses. It is essential to document this continuous learning process.

Three major sections of each Equipment Functional Specification were prepared:

> Anticipated Usage. This is a narrative functional description of application(s) in which the apparatus is to be used. This description may be applicable to several experimental activities and relates to the functional requirements derived from an examination of the generic SPA experiment classes in various R&D categories.
>
> Functional Requirements/Rationale. This is an explicit functional description of the apparatus under consideration. Particular descriptive content may include control functions, data output, power input, interface requirements and safety considerations.
>
> Specifications/Criteria. Where applicable and available, quantitative and qualitative information is included such as temperature ranges of interest, required accuracy of performance/control/measurement.

The collection of these functional specifications are planned to ultimately result in the issuance of an "Experimenter's Handbook" which in conjunction with other activities would assist the Principal Investigators in the planning and execution of their experimental programs.

The next issues at hand require that the equipment inventory be capable of being formed into payload configurations, which must be consistent with both the experimental objectives and the host-vehicle's accommodation modes. Additional issues have been examined and concepts have been developed for this to occur.

Mission Planning

Illustrating another important aspect of the payload accommodation requirement is the necessity of identifying and planning the range of values of interface requirements between the host-vehicle and payload equipment. Since the SPA discipline's objectives require a need to respond to ever-changing equipment complements as both experimental objectives and mission opportunities evolve, a system is needed to conveniently allow numerous permutations of the experiments and apparatus groupings to be characterized.

For each mission mode selected, overall layouts must be prepared which illustrate the payload equipment/host vehicle accommodation. Due to the enormous number of distinct combinations of experiments that may be performed in the various anticipated mission modes, a detailed analysis of the data requirements involved in each case will be mandatory. By using the results of such a planning program in the study of the experiment timelines, better usage of the available facilities may be made.

Confronted with a plethora of data, a means must be found by which an effective display may be prepared. One successful method of doing this has been found and involves the computer generation of three-dimensional bar graphs.

A TRW Systems computer program named BG3D makes a graphical display of a set of positive numerical values that are assigned to the separate grid squares of a rectangular grid. This procedure provides a highly effective method of visualizing a vast set of data - much better than by reading a matrix. By using the BG3D program and also by making use of some two-dimensional displays, a comprehensive study may be made of the many data requirements. Those singled out and analyzed initially are power, energy, weight and volume. Others may be added later, such as heat rejection, source power requirements, electromagnetic compatibility and data management.

Several files must be established from which data may be drawn in order to initiate the plots. These are:

- <u>Equipment Files</u>

For each piece of equipment in the SPA inventory a separate data record is established which includes weight, volume and power profile. If the equipment has both a sustained and peak power level, both are specified.

- <u>Experiment Files</u>

For each experiment to be performed a separate data record is established which includes a list of each piece of equipment used and its start-up and shut-down times.

- <u>Mission Files</u>

For each mission considered, a separate data record is established which includes the experiments being performed and their start times.

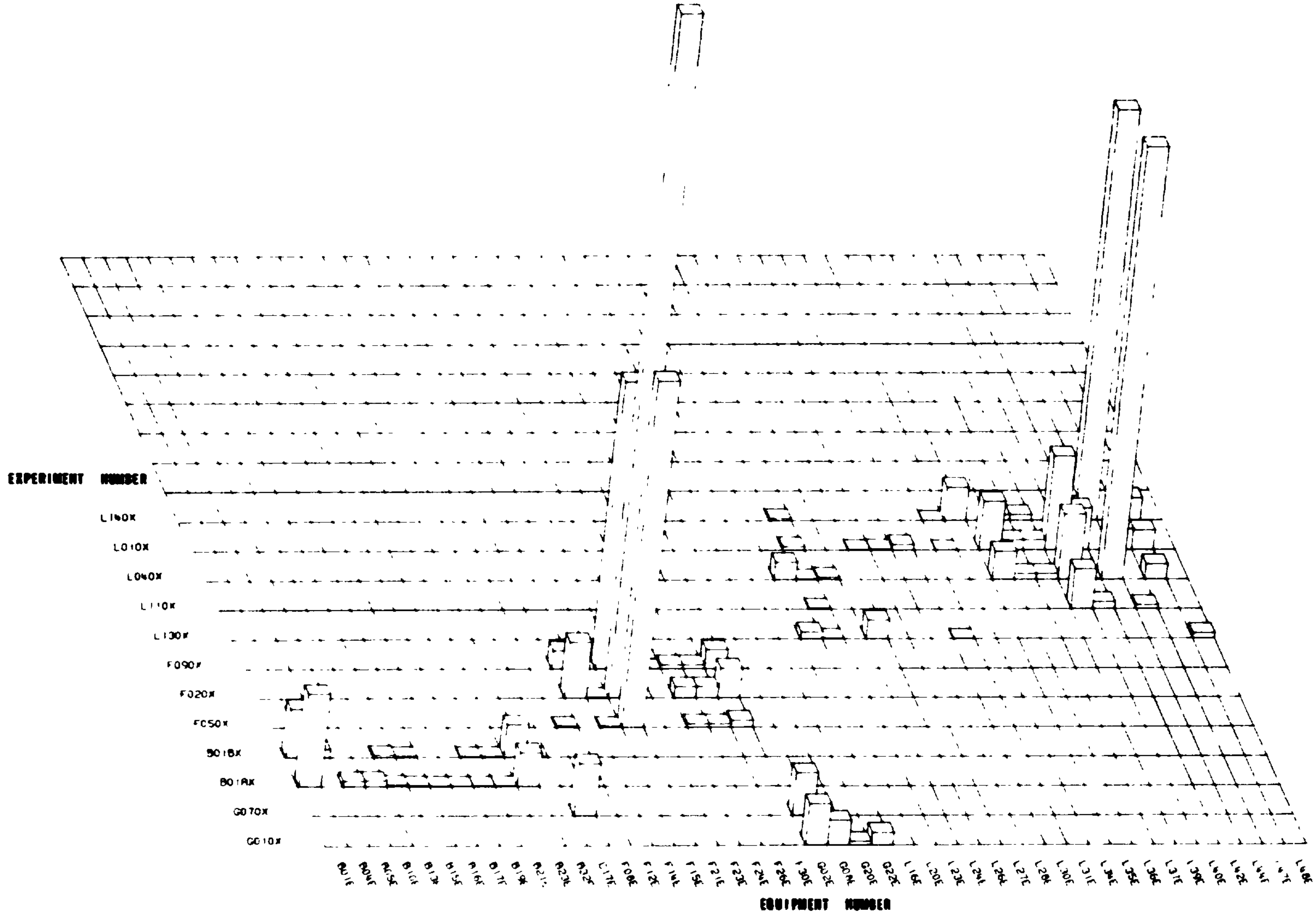
Illustrating an energy profile display for twelve (12) SPA experiments is the BG3D presentation shown in Figure 8.

INTEGRATION & INTERFACES

There are other aspects which are required in anticipating the payload designs and which compliment the concepts described in the prior paragraphs. The issues of not "what", but "how" must be addressed through early systems engineering and subsystems design analysis in order to

FIGURE 8. MISSION ENERGY BAR GRAPH

MISSION ENERGY – (1 INCH = 1 KILOWATT-HOUR)



ascertain the technical viability of the concepts. The major interfaces to the payload equipment that must be considered in these analyses are shown in Figure 9. Some of the main issues are summarized below.

Performance of Preliminary Engineering Analysis of Modular Payload Subelement/Host Vehicle Interfaces

Subsystem interface analysis was performed to establish the integrity of the modular approach to the equipment design and integration. Salient areas that were selected for analysis were power and power conditioning, heat rejection and electromagnetic capability (EMC).

Power and Power Conditioning

Earlier studies indicated that virtually all equipment requires special conditioning of the input power (high volt, low volt, regulation, etc). An examination of the input power available from the Spacelab indicated a possible mismatch in special equipment requirements for a majority of cases (including commercial equipment). Maximum flexibility in integrating subelements into the Spacelab may be achieved if the power conditioners are part of the payload equipment.

Based upon these conclusions, and in close correlation with the thermal and other aspects of payload design, efforts were directed at examining the power requirements that follow:

Power-Load Requirements

The number of possible SPA experiments are diverse. For the purpose of narrowing the scope of this study, the equipment and load profiles for twelve representative experiments were identified. These twelve SPA experiments are listed in Table II. Throughout, these twelve experiments will be identified by the numbers one through twelve. Two of the twelve experiments were chosen as being representative of the group and are illustrated in greater detail to describe the evaluations used in the analysis. They are Experiment #1, Metallurgical-Furnace, Encapsulated Immiscible Combination, and Experiment #8, Biology Applications-Continuous Flow Electrophoretic Separation of Proteins. The profiles of the power-source loads for these two representative experiments are presented in Figure 10.

Power Availability

The Shuttle Orbiter will provide electrical power from its three fuel cells in support of the Orbiter and the Spacelab operations. One of the three Shuttle Orbiter fuel cells is dedicated to the Spacelab electrical power requirements during normal Shuttle operation. This power supplies the Spacelab subsystems and the excess is available to the payload. The current Spacelab subsystem requirements result in a payload allocation of 4.0 to 4.8 KW average (24 hour/day) and 9.0 KW peak for 15 minutes.

FIGURE 9. SPA EXPERIMENT MODULE/HOST VEHICLE INTERFACE CONSIDERATIONS

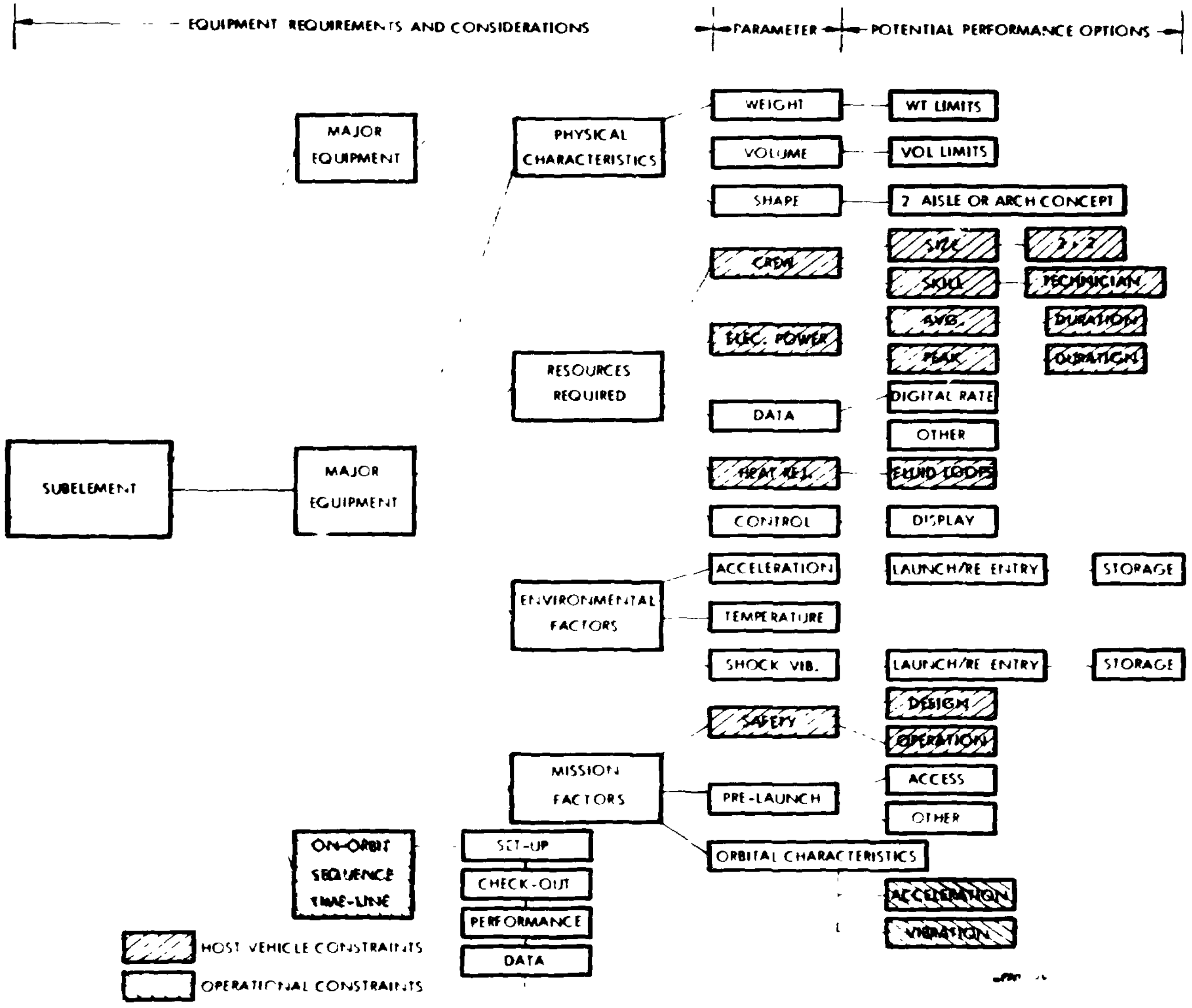
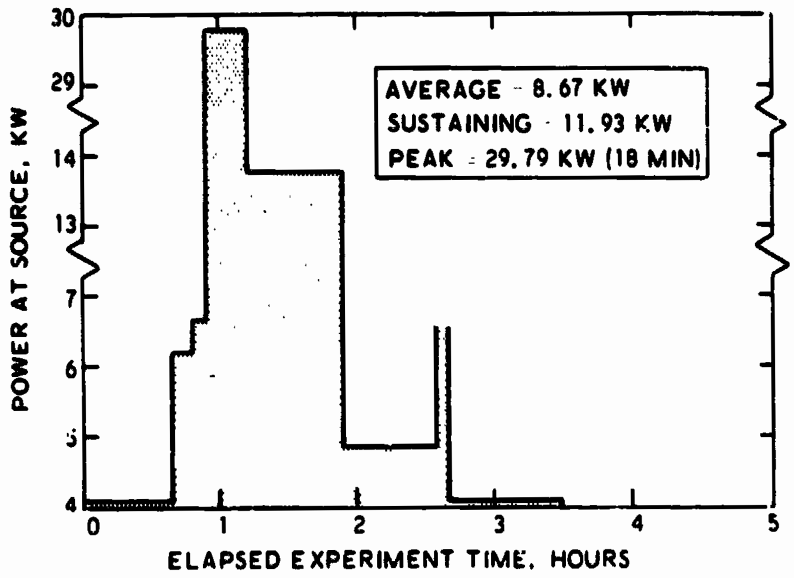


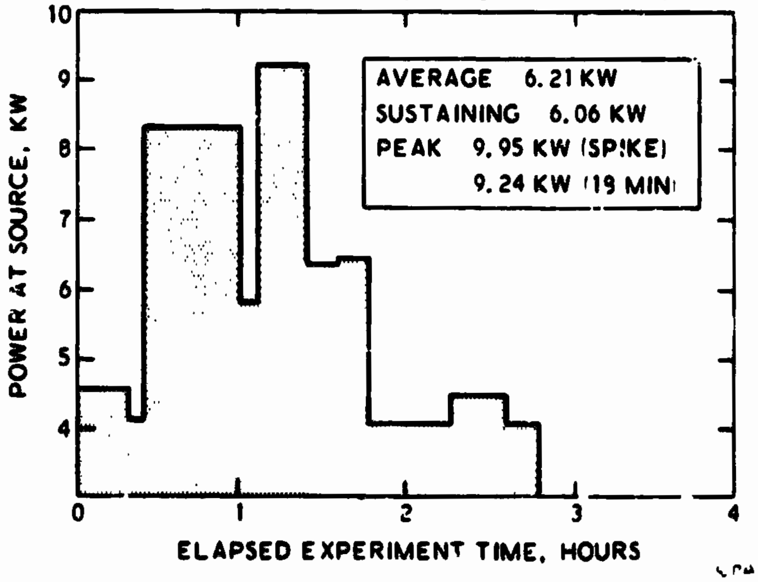
Table II. SPA Experiment Identification

No.	Exemplary SPA Experiment Class	R&D Category	Subelement
1.	Encapsulated Immiscible Combination	Metallurgical	Furnace
2.	Preparation of Pure Alloys - Containerless Melting	Metallurgical	Levitation
3.	Molten Zone Crystal Growth	Crystal Growth	Furnace
4.	Crystal Growth by Pulling from a Containerless Melt	Crystal Growth	Levitation
5.	Preparation of Multiphase, Silicate-Based Glass	Glass Technology	Furnace
6.	Containerless Preparation of La_2O_3-Based Glass	Glass Technology	Levitation
7.	Stationary Column Electrophoretic Separation of Proteins	Biology Applications	Biological
8.	Continuous Flow Electrophoretic Separation of Proteins	Biology Applications	Biological
9.	Containerless Position Control of Liquids by Electromagnetics	Physical Processes in Fluids	Levitation
10.	Thermal Gradient Convection in Liquids	Physical Processes in Fluids	General
11.	Chain Reactions Affected by Convection	Chemical Processes in Fluids	Levitation
12.	Radical Lifetimes	Chemical Processes in Fluids	General

FIGURE 10. SPA EXPERIMENT POWER SOURCE LOAD PROFILES



1. METALLURGICAL-FURNACE



8. BIOLOGY APPLICATIONS-CONTINUOUS FLOW

Additional power sources must be provided to fulfill electrical power requirements that exceed the allocation of electrical power from the Orbiter. The power sources considered were supplemental and/or peaking battery kits and the use of a Power-Heat Rejection Kit. The Kit may contain up to two Shuttle-type fuel cells and the necessary plumbing, controls, reactants and tankage to satisfy the SPA experiment requirements. The Power-Heat Rejection Kit would provide up to 14 KW of continuous power and peaks of up to 24 KW for 15 minutes.

The use of the experiment payload allocation from the Orbiter and the Power-Heat Rejection Kit can provide electrical power to the SPA experiments of from 4.0 to 18.8 KW continuously and peaks of up to 33 KW for 15 minutes.

For the purpose of assessing the capability of the electrical power allocations to satisfy the SPA experiment requirements, Figures 11 and 12 summarize the sustaining and peak experiment electrical power requirements at the source for each of the 12 illustrated experiments. These were used to provide a comparison with the power allocations from the Spacelab and a Power-Heat Rejection Kit as shown in Figure 13. These figures also compare the average and peak electrical power capabilities of one and two fuel cell systems.

Power Conditioning-Distribution

The electrical power conditioning and distribution subsystem must distribute power to the experimental equipment from the power source, in a safe, efficient manner. A number of concepts were considered and compared relative to:

1) Impact on subelement payloads
2) Impact on host vehicle (Spacelab)
3) Modularity/flexibility
4) Efficiency, weight and size
5) Safety
6) Electromagnetic Compatibility (EMC)

This comparison resulted in the following recommendations: A 115 VAC-400 Hz, single-phase system for the low power experiment bus, and a 115 VAC-1600/1800 Hz, 3-phase, 4-wire system for the high power experiment bus. A block diagram showing the power distribution system is shown in Figure 14. Power conversion from 28 VDC to 400 Hz and 1800 Hz AC is accomplished by static DC to AC inverters, which are frequency and phase synchronized to prevent dynamic interactions and system instability. The inverters are self-protecting for overvoltage on input and overload and short circuit on output. Further consideration will be given to the modularization of both the input and output junction boxes into several separate modules so that in case of a major fault some bus protection will be provided by the physical separation of the switching elements.

FIGURE 11. SUSTAINING EXPERIMENT POWER (AT POWER SOURCE)

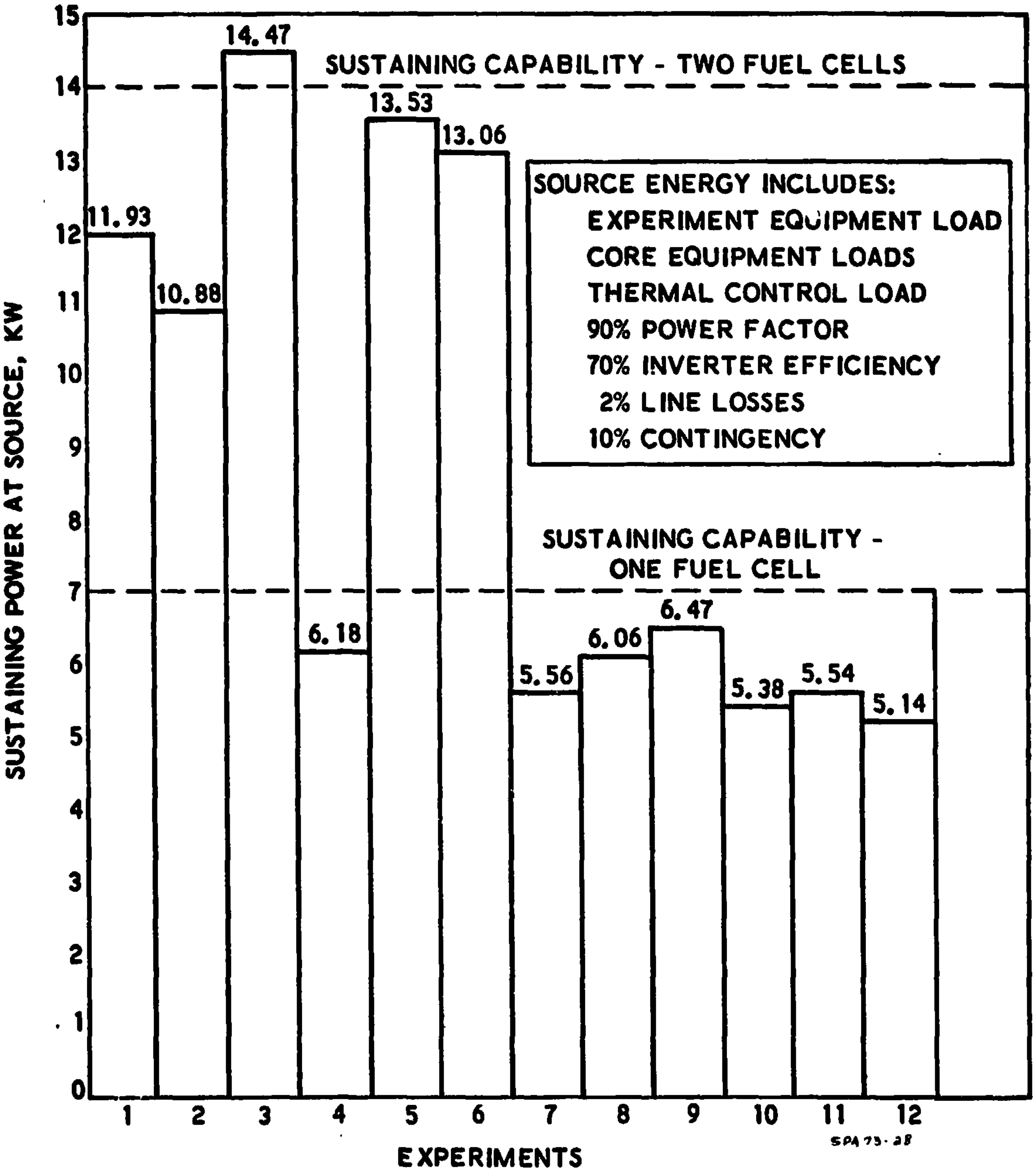


FIGURE 12. PEAK EXPERIMENT POWER (AT POWER SOURCE)

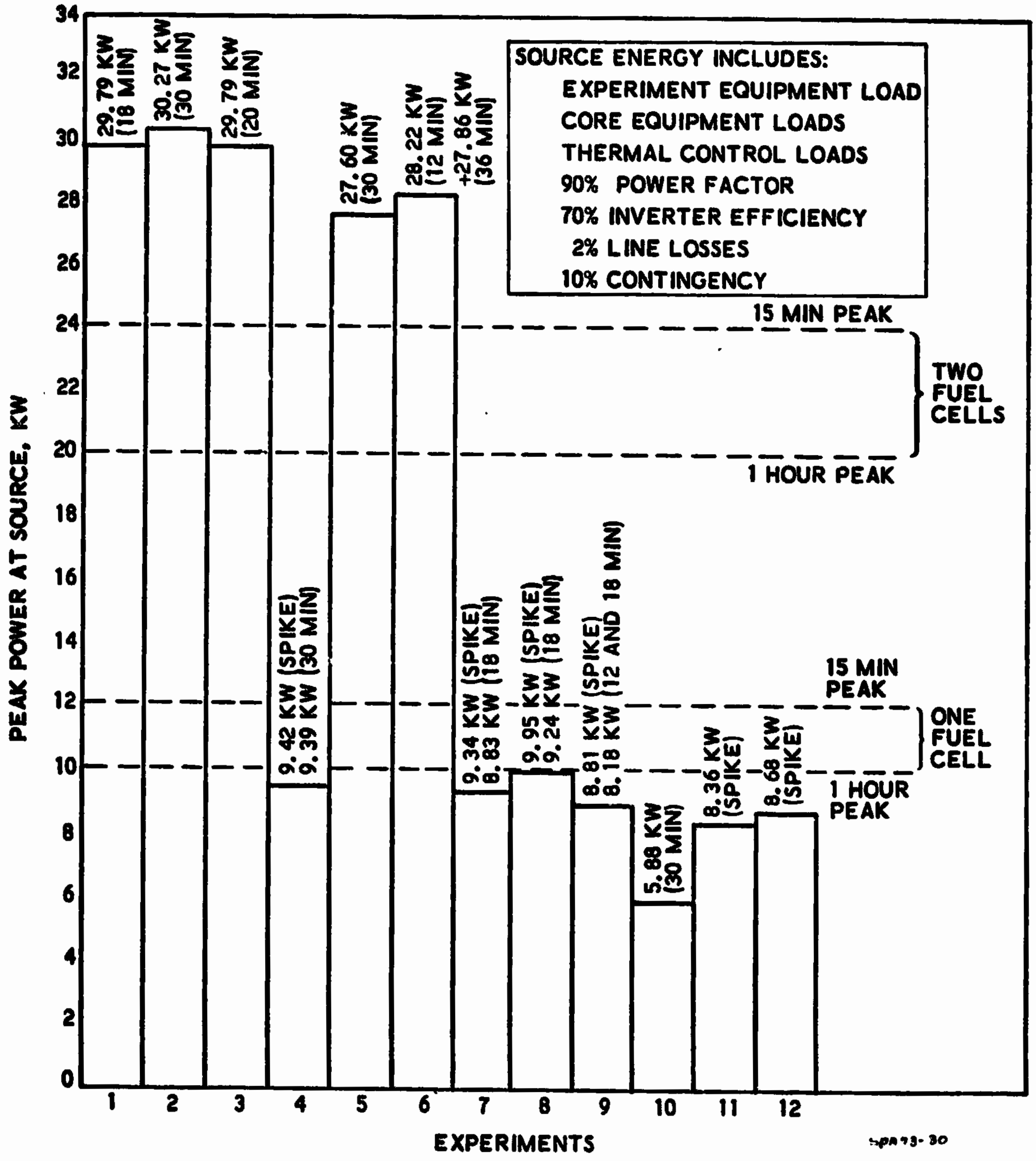


FIGURE 13. SPA EXPERIMENT POWER SOURCE ACCOMMODATION

EXPERIMENT NO.	EXPERIMENT NAME	POWER SOURCE CONCEPTS									
		1 SPACE LAB ALLOCATION ONLY[1]		2 POWER-HEAT REJECTION KIT ONE FUEL CELL[2]		3 SPACE LAB ALLOCATION PLUS POWER-HEAT REJECTION KIT ONE FUEL CELL		4 POWER-HEAT REJECTION KIT TWO FUEL CELLS		5 SPACE LAB ALLOCATION PLUS POWER HEAT REJECTION KIT TWO FUEL CELLS	
		AVERAGE 4 TO 4.8 KW	PEAK 9 KW	AVERAGE 7 KW	PEAK 12 KW[3]	AVERAGE 11 TO 11.8 KW	PEAK 21 KW	AVERAGE 14 KW	PEAK 24 KW	AVERAGE 18 TO 18.8 KW	PEAK 33 KW
1	METALLURGICAL - FURNACE							X		X	X
2	METALLURGICAL - LEVITATION					X		X		X	X
3	CRYSTAL GROWTH - FURNACE									X	X
4	CRYSTAL GROWTH - LEVITATION			X	X	X	X	X	X	X	X
5	GLASS TECHNOLOGY - FURNACE							X		X	X
6	GLASS TECHNOLOGY - LEVITATION							X		X	X
7	BIOLOGY APPLICATIONS - STATIONARY COLUMN		X	X	X	X	X	X	X	X	X
8	BIOLOGY APPLICATIONS - CONTINUOUS FLOW			X	X	X	X	X	X	X	X
9	PHYSICAL PROCESSES IN FLUIDS - LEVITATION		X	X	X	X	X	X	X	X	X
10	PHYSICAL PROCESSES IN FLUIDS - GENERAL		X	X	X	X	X	X	X	X	X
11	CHEMICAL PROCESSES - LEVITATION		X	X	X	X	X	X	X	X	X
12	CHEMICAL PROCESSES - GENERAL		X	X	X	X	X	X	X	X	X

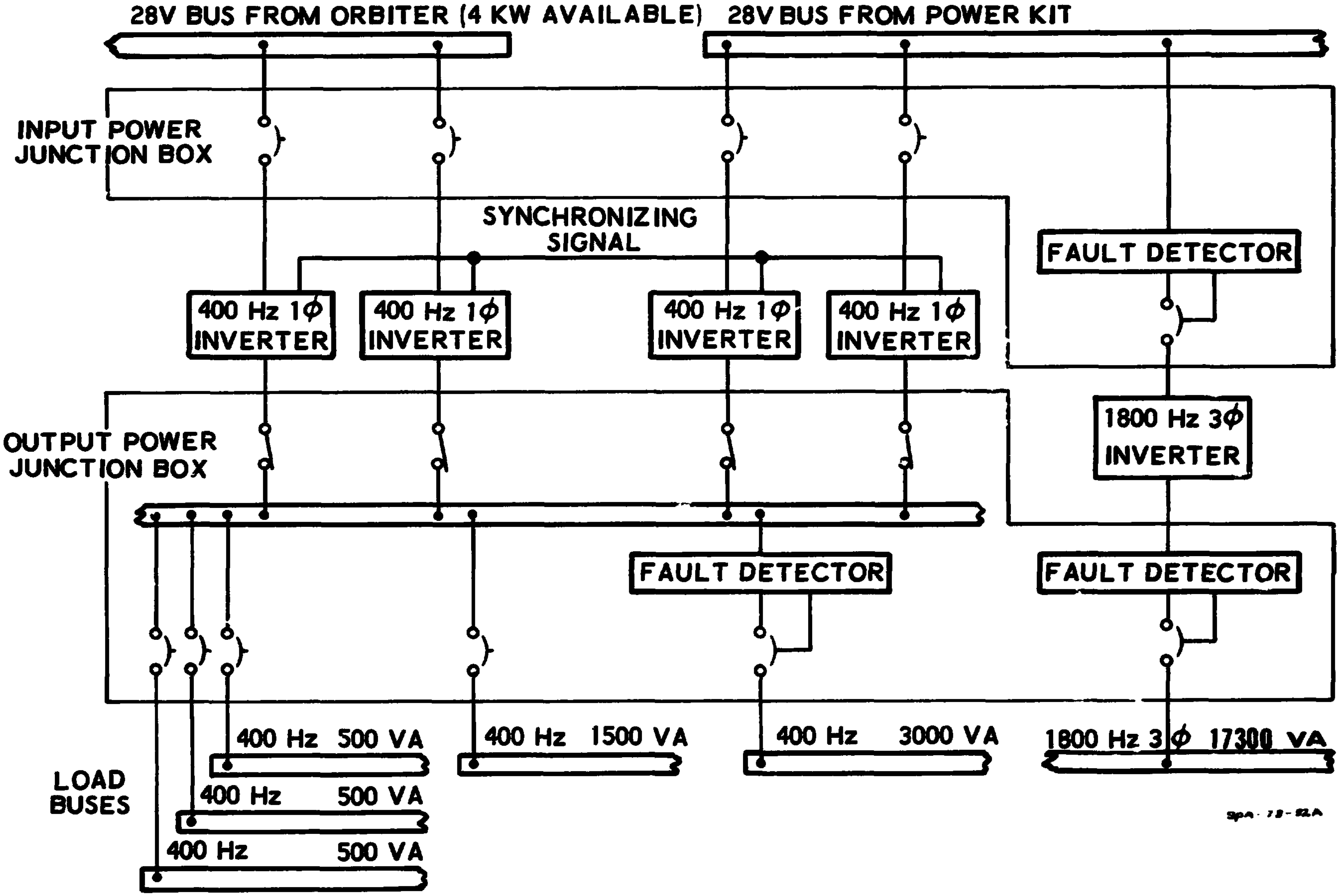
PA 73-31

NOTE:

1. SPACELAB, SUBSYSTEM SPECIFICATION, ISSUE 3, REVISION 2, ESRO, 1973 OCTOBER 15.
2. FUEL CELL POWERPLANT, PROCUREMENT SPECIFICATION, MC464-0115, SPACE DIVISION, NAR, 1973 MAY 10.
3. PEAK POWER CAPABILITY IS 12 KW for 15 MIN AND 10 KW FOR ONE HOUR PER FUEL CELL.

X-INDICATES THAT THE ALLOCATION CONCEPTS AVERAGE OR PEAK POWER CAPABILITIES SATISFY THE SUSTAINING PEAK POWER REQUIREMENTS, RESPECTIVELY, OF THE EXPERIMENT.

FIGURE 14. SPACE LAB POWER DISTRIBUTION



Of course, throughout this activity a continuous trade study of power conditioning and distribution equipment efficiencies on the thermal control requirements was made. Several thermal interfaces between the electrical power and thermal control subsystems were evaluated. The primary interface is the dissipation of all electrical energy consumed by the experiments, i.e., the energy under the experiment power source profiles must be dissipated by the thermal control subsystem. The dissipation of this energy requires additional electrical energy for operation of the thermal control equipment resulting in an increase in electrical energy that must be dissipated. Other thermal interfaces considered were the dissipation of heat from the fuel cells and the resultant by-product (water) produced by the fuel cells for potential use by the thermal control subsystem.

Thermal Performance Requirements

The thermal interface analysis was addressed in the following way:

Identification of Waste Heat Requirements:

The thermal control subsystem provides the required thermal protection to maintain all subsystems within thermal limits for all mission phases for the experimental equipment. Waste heat dissipation timelines were developed for the equipment selected in the subelements. The timelines were necessary to establish magnitude and duration of peak loads. Items of equipment that have waste heat requirements were separated into two groups: (1) those that can be met by the Spacelab capability, and (2) those items that require supplemental capability.

Identification of Special Interface Problems:

In addition to the amount of heat, some items of equipment were identified that must meet specific temperature requirements such as component touch or condensation temperature limits.

Thermal Control Cooling Concepts:

For the purpose of assessing the magnitude of the thermal control problem, three different thermal control system concepts were investigated to determine their capability to provide the necessary thermal control. Although the assessment was of a preliminary nature, the concept analyses did indicate a number of areas where modifications to SPA timelines and/or equipment would be necessary.

The air cooling system concept depends upon the Spacelab supplied air flow for cooling of rack mounted electronic equipment. In the analysis of this concept, a simplified thermal model of a typical cabin thermal control system and the SPA air cooling loop were generated, based upon the studies conducted at MSFC on the Sortie Lab. Based on the analyses to date, it appears that air cooling is feasible providing the necessary P/UA* can be provided on the commercial equipment.

The liquid cooling system is similar to the air cooling concept except that the equipment mounting rails in the rack are cooled by coolant lines. A parametric analysis was conducted to assess the feasibility of using a water cooling loop with cold plate mounted electronics. The liquid cooling concept's feasibility depends, to a large extent, on the design of the liquid distribution system. A properly designed system must be capable of providing the required flow rate at a low enough pressure drop to result in a reasonable pump power requirement. A complete assessment of the coolant loop characteristics would require a detailed thermal analysis for a specific configuration, however, it appears that a liquid cooling loop would be feasible.

A heat pipe system employed as a cooling concept for Spacelab was also investigated. Such a system would provide the capability of a thermal energy transport without an attendant expenditure of power for an electromotive device (fans, pumps, etc.). It was determined that the heat transport requirements on the heat pipe system that results from a typical rack power dissipation distribution are too severe. The number of pipes required were considered impractical in relation to air or pumped liquid cooling. Heat pipes can be used, however, for dumping heat from the various components into the air ducts.

Thermal Control Subsystem of Power/Heat Rejection Kit:

The Power/Heat Rejection Kit (PHRK) thermal control subsystem (TCS) consists of a pumped liquid loop which rejects thermal energy to space via a thermal radiator located on the exterior of the PHRK structure. One system studied uses dual radiators to reject the thermal energy absorbed from the fuel cells, electronic equipment and furnaces. The primary radiator is a high temperature radiator for high heat rejection and the secondary radiator is to provide temperature drop in approximately ten percent of the flow for cooling room-temperature operating, electronic equipment. A thermal capacitor is included in the system downstream of the primary radiator to store the thermal energy that exceeds radiator capacity until such a time as the thermal load falls within radiator capability. Such a system operates within duty-cycle limitations.

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*P = Component Power

UA = Effective Thermal Conductance From Component to Coolant

Figure 15 shows the PHRK heat dissipation model for those missions where the kit is in support of SPA payloads within the Spacelab. The heat rejection subsystem was baselined on a 7 ft. body mounted radiator length. The useable experiment duty cycle was then defined for this system versus the average experiment power involved. Subsequently, study of the heat rejection system designs required to operate at 7 kW and 14 kW electrical steady-state were analyzed. At the fuel cell sources, the previous electrical values reflect a steady-state heat rejection problem of 11.3 kW and 22.3 kW respectively. The steady-state approach to defining the use of a supplemental power and rejection kit represents an extreme usage limit. On the other hand, examination of possible duty cycle usages based upon average experiment power illustrates usage options with this approach. While the SPA experiment activities revolve around both power and energy availabilities, it can be conclusively shown that heat rejection will always pose the primary limitation in achieving the associated subsystem support. This is particularly true in light of the limitations affecting the thermal subsystem design of radiator size, fuel cell temperatures and use of capacitors.

Electromagnetic Compatibility

A preliminary activity was performed on the analysis of the electromagnetic compatibility (EMC) interface. Historically, EMC has been approached by testing engineering models per a military specification. In contrast, modeled payload analysis could be used to predict, characterize and provide trade solutions in the design activity. Most of the data required for detailed EMC study was not readily available. A beginning was necessary for two important reasons: one is that the problem area had to be opened up to establish the approach to EMC control, the other was that in order to exploit every mission opportunity, SPA payloads must be capable of operating in close proximity to almost any other experiment. An EMC evaluation of commercial equipment was one of the most important things to emerge from this effort, since commercial equipment of the kind envisioned by SPA has not considered EMC in the broad sense as necessary with space systems. This showed up in component design, component assembly techniques, and lack of measured or analytical EMC data. The EMC problem is further aggravated by the high currents and voltages required by SPA. The initial efforts have been aimed at various levels of categorization of the payloads and interfacing equipment and at the establishment of initial estimates for the EMC environment for the representative payload configurations. An illustrative test series was started to measure some of the pertinent EMC characteristics of R&D prototypes of equipment similar to that under consideration as potential SPA payloads.

One of the most prominent sources of steady-state radiated interference among the SPA candidate payloads is the induction heater. The induction heater's radiated interference can be expected to be a major consideration for the design of the Spacelab data handling and communication equipment.

FIGURE 15. POWER/HEAT REJECTION KIT HEAT DISSIPATION

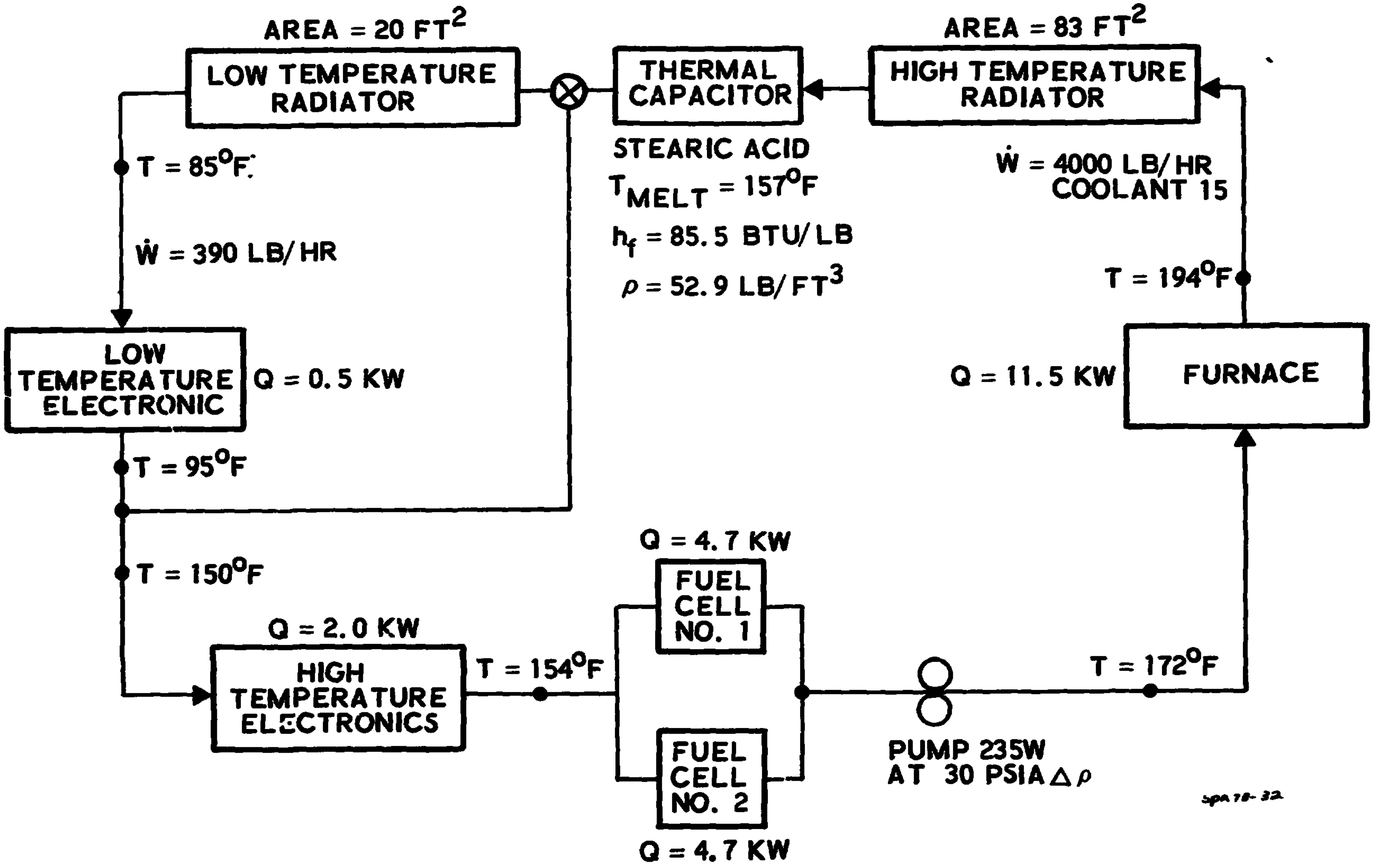


Figure 16 illustrates the levels of magnetic field radiation measured at a 1 meter distance from one of the two induction heaters tested.

Performance of an Analysis Regarding the Subject of Commercial Equipment Utility

An initial review of numerous payload equipment items showed that the functional requirements required of most of the apparatus are available from commercial sources. While the functional aspects are satisfied, other required usage factors that needed to be considered included outgassing or flammability of the materials, packaging and material substitution options, power conditioning, EMC and heat transfer. The ultimate host vehicle criteria imposed will profoundly influence the amount of modification necessary item by item, however, the commercial equipment design technology base remains the primary source of apparatus development. Even though, at the outset, the use of commercial equipment appeared potentially promising, a number of usage factors remained to be resolved. Specific factors that were examined included the following:

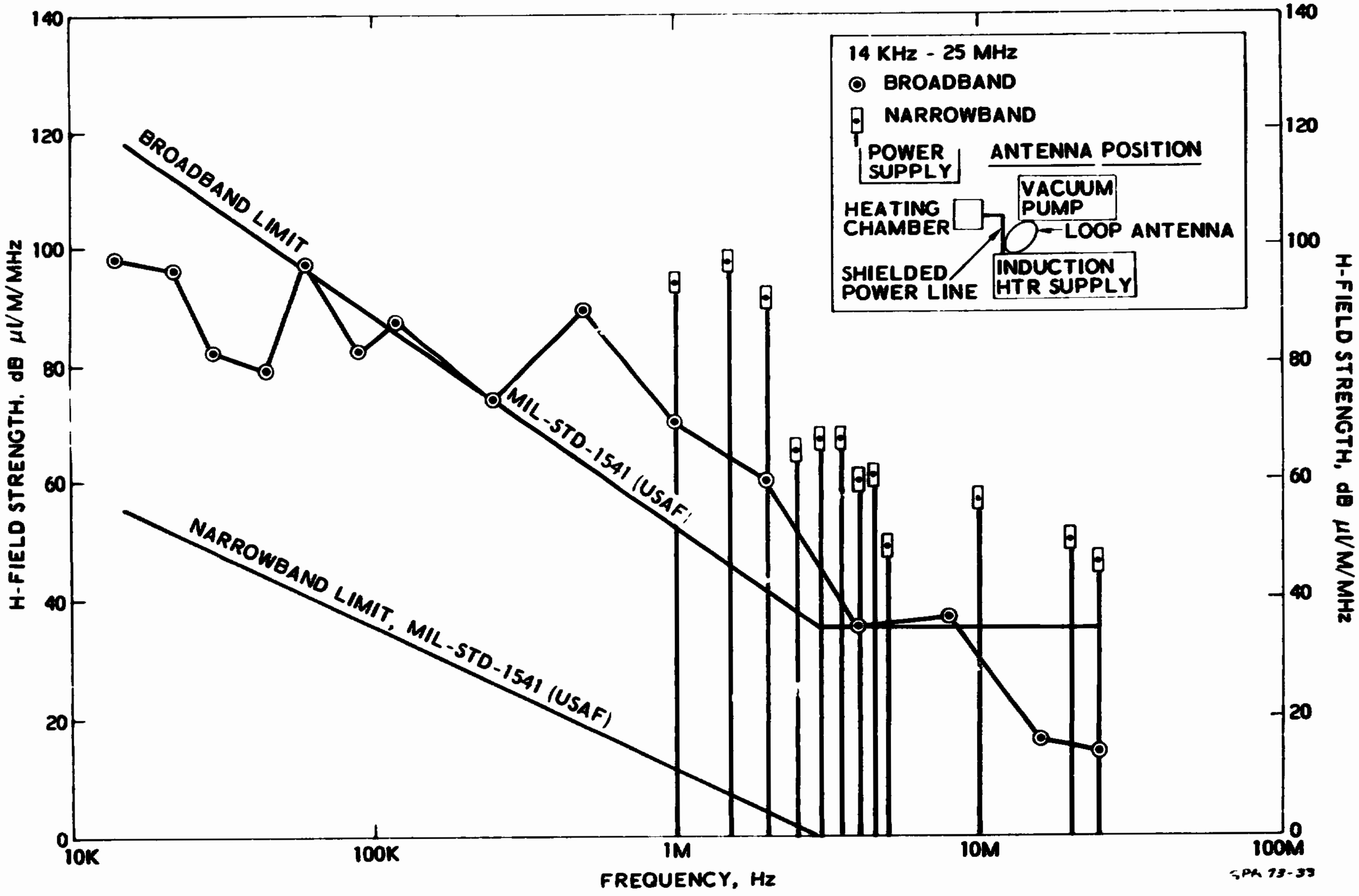
- Safety
- Packaging
- Structural
- Power Conditioning
- Thermal Control
- Materials of Construction

The list of commercial utility aspects were broken into three categories. The first category included the areas of packaging, structure, power conditioning and thermal. This group was concerned with questions related to the operational characteristics of the individual equipment item. In this sense judgements and assessments concerning the utility of a commercial piece of gear could be made, to a reasonable extent, by considering several typical equipment items. By example, the operational characteristics of a tube furnace produced by any one of several manufacturers could be used to assess such factors as the thermal, power and structural impacts upon the SPA payload. Certain aspects of the materials of construction such as the susceptibility to contamination deposits or shatterability also fall into this category.

In contrast, the second major category concerned questions relating to materials of construction, such as outgassing and flammability, which are to a much greater degree subject to variations from one manufacturer to another. These questions, in most cases, had to be considered on an individual item basis with respect to each specific equipment item and each specific manufacturer.

The third category was concerned with questions of safety. When an issue within the first two categories presented a potentially hazardous situation which had to be readily accepted, the problem was treated from the point of view of safety. Thus, where high voltage equipment was

FIGURE 16. HELMHOLTZ TYPE ELECTRON BEAM POWER SUPPLY (H-FIELD NARROWBAND AND BROADBAND RADIATED EMISSIONS, INDUCTION HTR 2)



considered necessary for performance of SPA missions requirements, suitable steps were determined to be required to assure crew and vehicle safety.

Specific equipment items analyzed were selected from the equipment inventory list using the following criteria:

- The equipment was representative of a type important to the success of future SPA missions
- Possible problem areas existed for Spacelab utilization
- Data availability

A number of specific items were selected for a detailed assessment. These items are as follows: Gas Chromatograph, Continuous Flow Electrophoresis Column, PH Monitor, Freezer/Refrigerator, Data Acquisition System, Chest-General Purpose Enclosure, Hot Wall Furnace, Zone Refiner, Dye Laser/Flash Lamp, High Voltage Power Conditioner, IR Pyrometer, Temperature Controller and Programmer. Because an officially approved NASA specification for equipment and material utilization in the Spacelab did not exist, a set of study criteria, drawn largely from existing NASA documents, were collected for use in bench-marking the utility assessment.

Any assessment of commercial utility considerations must be, in many instances, closely associated with a subsystem interface analysis activity. Coordination of the commercial utility assessment and the interface trade studies was thus required to optimize the information and results of the two efforts. Whenever possible, ongoing equipment considerations and interface studies[3] considered the same equipment items.

CONCLUSIONS

The basic approach to establishing SPA payloads is predicated upon the formulation of pregrouped modular subelements of equipment. A preplanned inventory of equipment, when coupled with modular integration concepts with an ability to readily reconfigure, can then serve the ongoing research needs of a world-wide group of investigators. As such, the typical flow of events expected are identified in Figure 17. The following overriding highlights summarize the SPA payload equipment requirements:

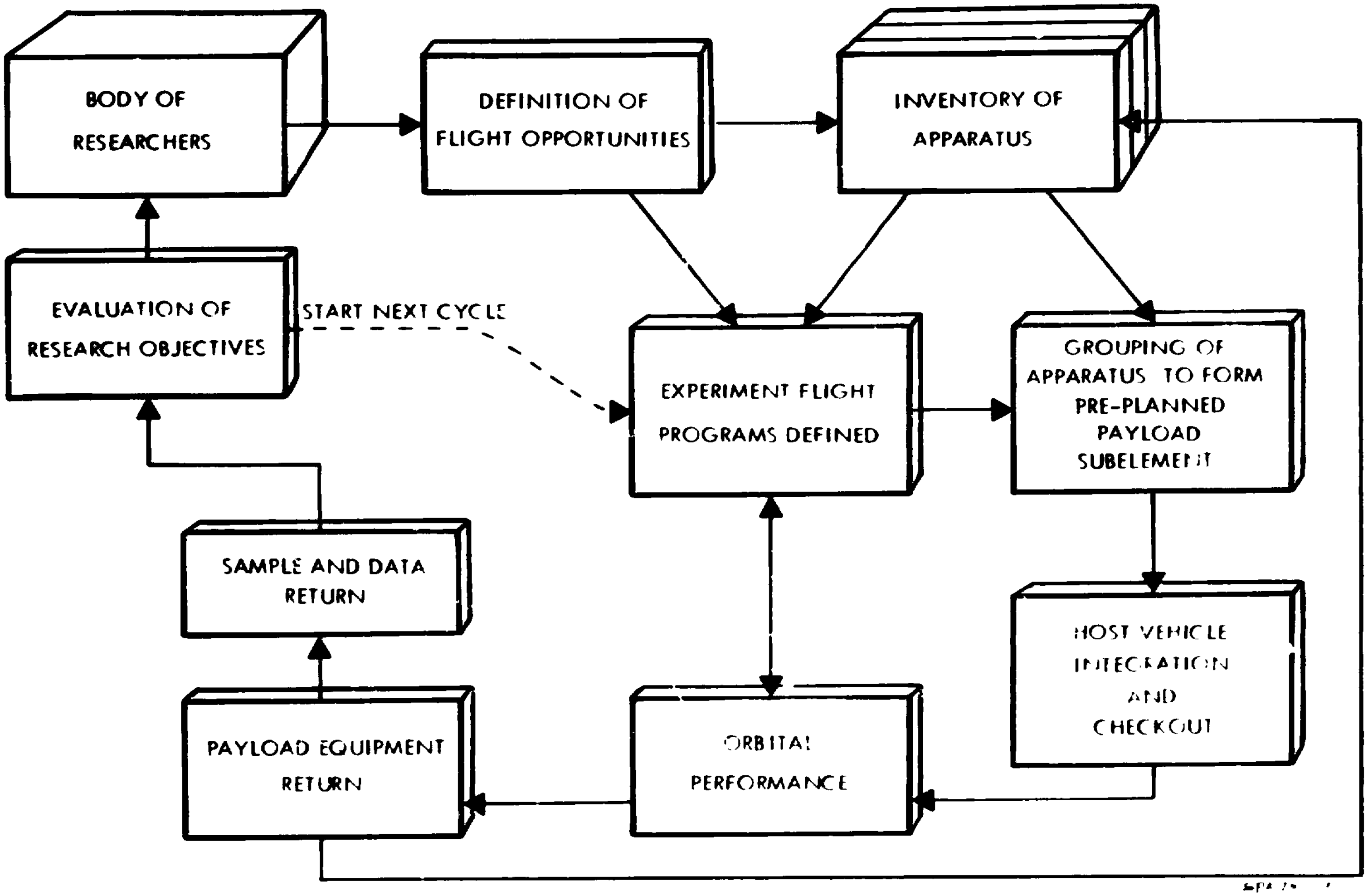
1) A multifacet/evolutionary program must be anticipated in space processing, spanning many years and numerous missions.

2) A comprehensive complement of equipment is required to support the projected ranges of R&D activities.

3) Grouping of equipment to form several self-contained payload subelements allows support of specific experimental classes either alone or in conjunction with each other.

4) Modular subelement approaches can allow the R&D technical program to range from austere to comprehensive in modular increments.

FIGURE 17. ILLUSTRATIVE FLOW OF EVENTS



5) It is essential to take advantage of every Shuttle flight opportunity and mandatory to have a continuous rematch of scientific interests, instrument capabilities and mission requirements.

6) It is necessary and desirable to derive the space processing equipment from within an existing multibillion dollar commercial technology industry, wherever possible.

Shuttle-supported space endeavors are visualized as portending a new era of equipment and capability development - an era in which the means and the methods used in prior times will be vastly modified through use of this new capability. Implementation of Shuttle-supported experimentation will certainly involve the continued identification and refinement of the methods. It is expected that the in-space activity will be largely concerned with development of experiment technique and equipment optimization, particularly in endeavors which are supported by shared-sortie payload concepts. Hand in hand with Shuttle system versatilities must be an associated implementation of simpler user interfaces.

The use of commercial equipment source derivations for many of the contemplated space activities provides not only for familiar user equipment interfaces, but reinforces the opportunity of achieving selective cost effectiveness through development of space payload equipment via a resource which to date has not been possible.

Many factors will undoubtedly impact the support available for establishing future space processing endeavors. Whatever these resources may be, it is expected that the process of learning how to use the Shuttle System and exploiting the evolution of Space Processing to be an active process for many years.

REFERENCES

1. Final Report of the Space Shuttle Payload Planning Working Groups - Vol. 9, "Materials Processing and Space Manufacturing", May 1973.

2. R. L. Hammel, "Use of Shuttle for Test of Experimental Hardware in Space". Presented AAAS-72 Annual Meeting, Washington, D.C.

3. Requirements and Concepts for Materials Science and Manufacturing in Space Payload Equipment Study. Vols. I, II and III. DCN No. 1-2-21-00172. S2, July 1973.

4. The October 1973 Space Shuttle Traffic Model, NASA/MSFC TMX-64751, January 1974.

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A GUIDE TO SPACE PROCESSING

SPA EXPERIMENT REQUIREMENT SUMMARY

EQUIPMENT CATEGORY	EQUIPMENT ITEM	R & D CATEGORY: BIOLOGICAL APPLICATIONS	CHEMICAL PROCESSES IN FLUIDS	CRYSTAL GROWTH	GLASS PREPARATION	METALLURGICAL PROCESSES	PHYSICAL PROCESSES IN FLUIDS	SUBELEMENT: BIOLOGICAL	[illegible]	FURNACE	GENERAL PURPOSE	LEVITATION	COMMONALITY / SUMMARY DATA: NO. REQD.	DIMENSIONS X (M)	DIMENSIONS Y (M)	DIMENSIONS Z (M)	WT. KG	VOL. M^3
ATMOSPHERIC COMPOSITION	FLUID SUPPLY SYSTEM C10E	●	●	●	●	●	●		●				1	61	.61	1 2	34.0	.447
	GAS CHROMATOGRAPH G16E, L34E		●	●	●	●					●	○	1	91	.91	30	22.7	.248
	HIGH VACUUM PUMP F25E, L45E			●		●				○		○	2	.30	.30	.46	22.7	041
	MOLECULAR SIEVE B27E, F28E, G28E, L46E	●		●		●		●		○	●	○	2	.15	.15	30	4.5	.007
	RESIDUAL GAS ANALYZER F12E, L35E			●	●	●				●		●	1	.24	.49	.52	34.0	.061
	VACUUM/PRESSURE MEASUREMENT UNIT F26E, G17E, L36E			●		●				○	●	○	1	.24	.49	.52	6 8	.061
	VACUUM/PRESSURE REGULATOR F24E, G18E, L37E			●		●				○	●	○	1	24	49	.52	9 1	.061
BIOLOGICAL PROCESS EQUIPMENT	CONTINUOUS FLOW ELECTROPHORETIC COLUMN B11E	●						○					1	.37	1 22	.10	4.53	.045
	DIALYSIS UNIT B9E	●						●					1	.30	.30	.30	4 5	.027
	DISSOLVED OXYGEN ANALYZER B19E	●						○					2	23	.21	.34	7.7	.016
	FLOW METER B17E	●						○					4	.03	03	09	.45	000
	FRACTION COLLECTION SYSTEM B16E	●						○					1	.37	09	45	9.0	.015
	ISOELECTRIC FOCUSING UNIT B31E	●						●					1	.27	03	03	1.36	000
	GAS ELIMINATION SYSTEM B13E	●						○					2	15	15	24	2 3	005
	LYOPHILIZATION UNIT B18E	●						●					1	76	55	37	90.6	155
	PH MONITOR B15E, G13E	●	●					○			●		1	.37	46	30	10 0	051
	PUMPS (METERING) B10E	●						○					2	.18	18	45	10 0	015
	RECIRCULATING FLUID INCUBATOR B8E	●						●					1	90	60	.60	9 0	324
	REGULAR BUFFER SUPPLY & ELECTROLYTE SUPPLY TANK B14E	●						○					4	15	15	.15	1 36	003
	STATIONARY ELECTROPHORETIC COLUMN B12E	●						●					5	27	03	03	1 36	.000
CONTAINERLESS POSITION CONTROL EQUIPMENT	CONTAINERLESS POSITION CONTROL SYSTEM																	
	ACOUSTIC TRANSDUCER & DETECTOR L16E		●		●	●	●					○	1	.30	30	30	11 3	027
	ELECTROMAGNETIC POSITIONING COILS & DETECTOR L14E		●	●	●	●	●					●	1	30	30	30	11 3	027
	ELECTROSTATIC POSITIONING PROBES & DETECTOR L15E		●	●	●	●	●					●	1	30	30	30	11 3	027
	GAS JET PROBES & DETECTOR L17E			●	●	●						●	1	30	30	30	11 3	027
COOLING EQUIPMENT	COOLANT SUPPLY TANK B29E	●						●					1	21	42	42	4 5	037
	DIRECTIONAL SOLIDIFICATION UNIT F4E					●				●			1	30	46	30	18 1	041
	FLUID COOLING/REFRIGERATION UNIT B1E	●						○					1	1.34	82	94	180 0	1 033
	SAMPLE COOLING CHAMBER F5E					●				●			1	30	46	30	18 1	041
	SAMPLE STORAGE AND PRESERVATION OF BIOLOGICALS																	
	DEWAR B25E	●						●					1	54	84	30	22 [illegible]	136
	FREEZER B24E	●						●					1	54	84	30	80 0	.136
	REFRIGERATOR B23E	●						○					1	54	84	61	57 0	277
DATA ACQUISITION AND CONTROL EQUIPMENT	DATA ACQUISITION UNIT																	
	DIGITAL CLOCK C1E	●	●	●	●	●	●		●				1	37	15	43	11 3	024
	DIGITAL VOLTMETER C4E	●	●	●	●	●	●		●				1	37	15	43	18 1	024
	MULTIPLEXER A/D CONVERTER C14E	●	●	●	●	●	●		●				1	52	18	49	27 2	046
	PRINTER (OUTPUT) C9E	●	●	●	●	●	●		●				1	37	30	43	22 7	048
	SCANNER PROGRAMMER C2E	●	●	●	●	●	●		●				1	37	15	43	9 1	.024
	SET POINT CONTROLLER C5E	●	●	●	●	●	●		●				1	37	24	43	22 7	038
	SIGNAL CONDITIONER C3E	●	●	●	●	●	●		●				1	52	34	49	27 2	087
	DATA CONTROL UNIT																	
	ANALOG (SCR) CONTROLLER C13E	●	●	●	●	●	●		●				1	52	37	49	15.9	094
	DIGITAL STORAGE C12E	●	●	●	●	●	●		●				1	.68	.30	.49	[illegible]	[illegible]
	INPUT/OUTPUT STAGE C7E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	OPERATOR CONTROL UNIT C8E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	PROCESSOR UNIT C6E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	STORAGE PERIPHERALS C16E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	TAPE INPUT C15E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		●				1	[illegible]	[illegible]	.49	22.7	[illegible]
	TELEPRINTER C11E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		●				1	[illegible]	[illegible]	.34	22.7	[illegible]
	ELECTRO-OPTICAL IMAGING SYSTEM C17E																	
	AUTOMATIC PROCESSOR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	●		●				[illegible]	[illegible]	[illegible]	.61	[illegible]	[illegible]
	CCTV CAMERA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	●		●				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	CAMERA CONTROL UNIT	[illegible]	[illegible]	[illegible]	[illegible]	●	●		●				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	FRAME STORAGE UNIT	[illegible]	[illegible]	[illegible]	[illegible]	●	●		●				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FOLDOUT FRAME

2

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

ESSING PAYLOADS FOR SHARED MISSIONS*

SUMMARY DATA

NO. REQD.	DIMENSIONS X (M)	Y (M)	Z (M)	WT. KG	VOL. M³	POWER (WATTS) PEAK	SUS.	DATA BPS
1	.61	.61	1 2	34.0	.447	-	-	-
1	.91	.91	30	22.7	.248	300	300	02
2	.30	.30	.46	22.7	041	1000	50	40
2	15	.15	30	4 5	.007	-	-	-
1	.24	49	52	34 0	.061	250	250	02
1	.24	.49	.52	6 8	.061	100	50	02
1	24	49	.52	9.1	061	100	50	02
1	37	1 22	.10	4.53	.045	•	•	-
1	30	.30	30	4 5	.027	100	100	01
2	23	21	34	7.7	.016	15	15	10
4	03	03	09	.45	000	10	10	10
1	.37	09	45	9.0	.015	50	50	01
1	.27	03	03	1 36	000	•	•	-
2	15	15	24	2 3	.005	50	50	10
1	.76	55	37	90 6	.155	600	200	01
1	37	46	.30	10 0	051	20	20	01
2	18	18	45	10 0	.015	-	100	10
1	90	60	.60	9 0	.324	200	10	01
4	.15	15	15	1 36	003	-	-	-
5	27	03	03	1 36	000	•	•	-
	.30	30	.30	11 3	027	-	200	10K
	30	30	30	11 3	027	-	200	10K
	30	30	30	11 3	027	-	200	10K
	30	30	30	11 3	027	-	200	10K
	21	42	42	4 5	037	-	-	-
	30	46	30	18 [illegible]	041	-	-	02
	1 34	82	94	180 0	1 033	750	750	02
	30	.46	30	18 1	041	-	-	40
	54	84	30	22 7	136	-	-	-
	54	84	30	80 0	.136	500	100	-
	54	84	61	57 0	277	250	50	-
	37	15	43	11 3	024	-	100	-
	37	15	43	18 1	.024	-	100	-
	52	18	.49	27 2	046	-	100	-
	37	[illegible]	43	22 7	048	-	400	-
	37	[illegible]	43	9 1	024	-	20	-
	.37	24	43	22 7	038	-	100	-
	52	34	49	27.2	087	290	35	-
	.52	37	49	15.9	094	-	100	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	150	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
	[illegible]	[illegible]	49	22 7	[illegible]	[illegible]	[illegible]	-
	[illegible]	[illegible]	34	22.7	[illegible]	[illegible]	[illegible]	-
	[illegible]	[illegible]	.61	22.4	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	125	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	140	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	20	[illegible]
	.21	[illegible]	[illegible]	[illegible]	[illegible]	-	100	[illegible]
	.24	[illegible]	[illegible]	[illegible]	[illegible]	-	100	[illegible]

REVISED 5/22/74

REQUIREMENTS FOR COMBINATIONS OF MAXIMUM/MINIMUM EQUIPMENT SUBELEMENTS

SUBELEMENT COMBINATION (MINIMUM SUBELEMENT COMBINATIONS GIVEN IN PARENTHESES)	WEIGHT[9] (KG)	WEIGHT[9] (LB)	VOLUME[9] (M³)	VOLUME[9] (FT³)	POWER SUS. (KW) [8]	POWER AVERAGE (KW) [7]	POWER PEAK (KW) [6]	DURATION PER CYCLE AT AVERAGE POWER (HR) [5]	DURATION PER CYCLE AT PEAK POWER (HR)	AVERAGE ENERGY PER CYCLE (KWH) [4]	CYCLES PER MISSION	TOTAL EXPER'T ELAPSED TIME (HR) [3]	TOTAL HOURS PER MISSION (HR) [2]	TOTAL ENERGY PER MISSION (KWH) [1]
BIOLOGICAL (B)	809	1780	4.3	150	1.8	0.95	2.75	1.68	0.15	1.6	13	21.8	23.3	22
(MINIMUM-b)	(404)	(898)	(3.0)	(106)	(1.8)	(1.34)	(1.71)	(4.1)	(0.10)	(5.5)	(1)	(4.1)	(4.9)	(5.5)
FURNACE (F)	529	1160	2.8	100	5.0	4.22	11.3	3.75	0.20	15.8	16	60.0	61.8	254
(MINIMUM-f)	(181)	(401)	(1.1)	(39)	(1.9)	(2.84)	(10.7)	(4.5)	(0.5)	(12.8)	(1)	(4.5)	(5.2)	(12.8)
GENERAL PURPOSE (G)	586	1290	3.4	120	1.7	2.56	1.44	4.45	2.00	11.4	9	40.0	41.1	103
(MINIMUM-g)	(230)	(510)	(2.3)	(81)	(0.56)	(0.47)	(1.33)	(1.8)	(0.1)	(0.85)	(1)	(1.8)	(2.4)	(0.85)
LEVITATION (L)	1180	2600	4.8	169	6.0	5.05	14.0	3.68	0.30	18.6	12	44.2	47.0	224
(MINIMUM-l)	(282)	(627)	(1.9)	(67)	(2.12)	(3.16)	(4.56)	(3.8)	(1.0)	(12.0)	(1)	(3.8)	(4.4)	(12.0)
CORE (C)	518	1140	3.1	110	1.8	1.8	0.7	[10]	0.25	[11]	[11]	[11]	[11]	[11]
B+C	1330	2920	7.4	260	3.6	2.76	2.74	1.68	0.15	4.95	13	21.8	24.3	64.4
(b+c)	(922)	(2040)	[illegible]	[illegible]	[illegible]	(3.15)	(3.70)	(4.1)	(0.1)	(12.9)	(1)	(4.1)	(5.9)	(12.9)
F+C	1050	2300	5.9	210	6.8	6.03	11.3	3.75	0.20	22.6	16	60.0	62.8	362
(f+c)	(699)	(1540)	(4.2)	(148)	(3.7)	(4.64)	(10.7)	(4.5)	(0.5)	(20.9)	(1)	(4.5)	(6.2)	(20.9)
G+C	1100	2430	6.5	230	3.5	4.36	1.44	4.45	2.00	19.4	9	40.0	42.1	175
(g+c)	(748)	(1650)	(5.4)	(191)	(2.36)	(2.27)	(1.33)	(1.8)	(0.1)	(4.09)	(1)	(1.8)	(3.4)	(4.09)
L+C	1700	3740	7.9	279	7.8	7.20	13.6	3.68	0.30	25.2	12	44.2	48.0	303
(l+c)	(800)	(1770)	(5.0)	(177)	(3.92)	(4.95)	(4.57)	(3.8)	(1.0)	(18.8)	(1)	(3.8)	(5.4)	(18.8)
B+F+C	1860	4090	10.2	360	6.2	5.18	12.1	2.82	0.20	14.6	29	81.8	86.1	424
(b+f+c)	(1100)	(2440)	(7.2)	(254)	(3.7)	(3.93)	(11.4)	(4.3)	(0.5)	(16.9)	(2)	(8.6)	(11.1)	(33.8)
B+G+C	1910	4220	10.8	380	3.5	3.85	1.95	2.81	2.00	10.8	22	61.8	65.4	238
(b+g+c)	(1150)	(2450)	(8.4)	(297)	(3.3)	(2.83)	(2.02)	(3.0)	(0.1)	(8.5)	(2)	(5.9)	(8.3)	(17.0)
B+L+C	2510	5530	12.2	429	6.8	5.54	15.3	2.64	0.30	14.6	25	66.0	71.3	365
(b+l+c)	(1200)	(2670)	(8.0)	(282)	(3.8)	(3.98)	(5.54)	(4.0)	(1.0)	(15.9)	(2)	(7.9)	(10.3)	(31.7)
F+G+C	1630	3600	9.3	330	5.3	5.35	12.0	4.00	0.20	21.4	25	100	104	535
(f+g+c)	(929)	(2050)	(6.5)	(229)	(3.3)	(3.94)	(11.4)	(3.2)	(0.5)	(12.6)	(2)	(6.3)	(8.6)	(25.1)
F+L+C	2230	4900	10.7	379	7.2	6.36	14.4	3.73	0.30	23.7	28	104	110	664
(f+l+c)	(981)	(2170)	(6.1)	(215)	(3.8)	(4.74)	(10.6)	(4.2)	(0.5)	(19.9)	(2)	(8.3)	(10.6)	(39.8)
G+L+C	2280	5040	11.3	399	5.5	5.66	15.1	4.01	0.30	22.7	21	84.2	87.1	47
(g+l+c)	(1030)	(2280)	(7.3)	(258)	(3.5)	(4.11)	(5.41)	(2.8)	(1.0)	(11.5)	(2)	(5.6)	(7.8)	(23.0)
B+F+G+C	2440	5380	13.6	480	5.1	4.92	12.4	3.19	0.20	15.7	38	122	127	598
(b+f+g+c)	(1330)	(2950)	(9.5)	(335)	(3.5)	(3.60)	(11.7)	(3.5)	(0.5)	(12.6)	(3)	(10.4)	(13.5)	(37.8)
B+G+L+C	3090	6820	15.6	549	5.3	5.08	15.7	3.11	0.30	15.8	34	106	112	538
(b+g+l+c)	(1430)	(3180)	(10.3)	(364)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(3)	[illegible]	(12.7)	(35.8)
B+F+L+C	3040	6700	15.0	529	6.8	5.77	15.0	3.08	0.30	17.8	[illegible]	[illegible]	133	729
(b+f+l+c)	(1390)	(3070)	(9.1)	(321)	(3.8)	(4.27)	(11.0)	(4.1)	(0.5)	(17.5)	(3)	(12.4)	(15.5)	(52.6)
F+G+L+C	2810	[illegible]	[illegible]	[illegible]	6.0	5.29	15.0	3.91	0.30	22.7	37	144	151	840
(f+g+l+c)	(1210)	[illegible]	[illegible]	[illegible]	[illegible]	(4.29)	(11.0)	(3.4)	(0.5)	(14.6)	(3)	(10.1)	(13.0)	(43.8)

REMARKS

[illegible] CH INDIVIDUAL SUBELEMENT TO THE ENERGY NEEDED BY THE CORE. THE CORE ENERGY IS DETERMINED [illegible] OPERATIONS) TO THE RESPECTIVE 'TOTAL EXPERIMENT ELAPSED TIME' [3] AND MULTIPLYING THIS BY

INC [illegible] ERIMENT PREPARATIONS, OPERATIONS AND POST ACTIVITY PLUS INITIAL AND TERMINAL OPERATIONS.

·] INC [illegible] EXPERIMENT PREPARATIONS, OPERATIONS AND POST ACTIVITY

	MONITOR					●	●		●											[illegible]	
	SLOW SCAN SYNC & SWEEP					○	○		●										-	20	
	NUCLEAR PARTICLE COUNTING UNIT G25E														.21				-	100	
	OSCILLOSCOPE C18E								●						.24				-	100	
	TIME LAPSE/HIGH SPEED CAMERA G22E, L44E														.30	46			100	100	
ENCLOSURES/FURNACES	CHEST-GENERAL PURPOSE ENCLOSURE F3E ..., L4E				○	●	●			●	●	○		.46	46	46	[illegible]	[illegible]	[illegible]	-	[illegible]
	GLOVE BOX B30E, G3E	●					●	●			●		1	61	61	1 22	45 4	454	-		-
	GRADIENT FURNACE F20E					●				●			1	30	61	30	45 4	.055	9000*	5000*	-
	HOT WALL FURNACE (1800°C) F2E, L2E									●		●	1	30	.61	.30	45.4	055	9000*	5000*	-
	HOT WALL TUBE FURNACE (1200°C) F1E, G1E, L1E											●	[illegible]	30	.61	[illegible]	[illegible] 4	.055	1600*	[illegible]00*	-
	THERMAL OVEN G2E, L3E											●	[illegible]	30	[illegible]	[illegible]	[illegible]	041	300	300	-
HEAT FLUX MONITOR	DIRECTIONAL CALORIMETER L22E			●		●						●	1	15	15	.15	13 6	003	3	3	10
HEATING UNITS	ELECTRON BEAM SOURCE L7E			●	●							●	1	15	15	15	2 3	003	-	6000*	-
	LASER SOURCE L9E			●	●	●						●	1	61	61	91	362 9	339	-	6000*	-
	MICROWAVE HEATER F19E, G4E, L11E			●	●	●				●	●	◉	1	46	46	46	68 0	097	2000*	200*	50
	MINIMUM B WITH RF HEATING L10E			●	●	●						●	1	.30	30	30	4 5	027	2000*	200*	10
	RF INDUCTION COILS L6E			●	●	●						●	2	15	15	15	4 5	003	- *	2000*	-
	RESISTANCE HEATER (CONTACT) F18E, G27E					●				◉	●		1	06	06	15	1 4	001	- *	- *	-
	RESISTANCE HEATER (NON-CONTACT) L5E			●	●	●						●	1	15	15	15	4 5	003	- *	- *	-
MANIPULATION AND DISPLACEMENT UNIT	FEED & CRYSTAL HOLDER F11E, L28E			●		●				●		●	1	.15	91	.15	15 9	020	100	25	20
	PIEZOELECTRIC DRIVE F23E, L27E			●		●				●		●	4	10	10	61	9 1	006	50	5	100
	THREE-AXIS MANIPULATOR F22E, L26E			●		●				●		●	2	15	15	15	4 5	003	50	50	20
	ZONE REFINER F10E					●				●			1	30	46	30	4 5	041	6000	100-6000	40
MIXING AND DISPERSAL UNIT	ACOUSTIC F6E, L12E		●		●	●				●		●	1	18	18	18	9	006	-	50*	-
	ELECTROMAGNETIC F7E, L13E		●		●	●				◉		●	1	18	18	18	9	.006	-	50*	-
	MECHANICAL F21E					●				●			1	03	03	03	2 3	000	100	25	02
OPTICAL EQUIPMENT	DARK FIELD ILLUMINATOR B22E, G11E	●	●				●	●			●		1	05	03	03	2 3	000	[illegible]	[illegible]	[illegible]
	DYE LASER/FLASH LAMP B6E, G9E, L24E	●	●	●	●		●	●			◉	●	1	1 22	31	31	9[illegible] 7	117	100	50-1000	[illegible]
	IR SPECTROMETER G8E		●								◉		1	30	91	15	45 4	041	200	200	20
	LASER OPTICAL SCATTERING MONITOR B4E, G6E, L23E	●	●	●	●		●	●			●	◉	1	30	61	15	11 3	027	200	200	-
	RETRORECONSTRUCTION HIGH RESOLUTION HOLOMICROSCOPE B7E, G10E, L25E	●	●	●	●		●	●			●	●	1	30	30	46	13 6	041	50	50	-
	UV-VIS SPECTROMETER B5E, G7E	●	●					◉			●		1	30	61	21	45 4	038	200	200	20
POWER CONDITIONING	HIGH VOLTAGE (5KV) B21E	●						◉					2	28	19	19	9 0	010	200	20	20
	HIGH VOLTAGE (17KV) F27E, G20E, L41E				●	●				●	◉	◉	1	30	30	30	27 0	027	6000	100-6000	20
	LOW VOLT/HIGH AMP F15E, G24E, L42E			●	●	●				◉	●	●	1	30	46	46	40 8	063	9000	4000	20
	RF INDUCTION (2KHz - 2MHz) F29E, L39E			●	●	●				●		◉	1	30	30	30	16 0	027	2000	200	30
	RF INDUCTION (MIXING & DISPERSAL) F14E, L40E		●		●	●				◉		●	2	15	15	15	2 7	003	250	25	20
	VACUUM PUMP POWER CONDITIONER F30E, L47E			●		●				◉		◉	[illegible]	[illegible]	[illegible]	49	13 6	046	000	100	-
SAMPLE PLACEMENT AND RETRIEVAL	INERTIAL INJECTOR L31E			●		●	●					●	1	.12	12	15	9	.002	10	1	02
	LIQUID SYRINGE DISPENSER G15E, L30E			●							●	●	1	03	03	30	5	000	50	10	02
	MECHANICAL L29E			●		●	●					◉	1	.03	03	30	5	.000	-	-	-
	SOLID SAMPLE STORAGE L33E			●	●	●						●	1	**	**	**	**	**	-	-	-
	SPECIMEN/SAMPLE SUPPLY TANKS B20E	●						◉					14	05	.05	05	45	000	-	-	-
	VACUUM CATCH TUBE L32E			●		●	●					●	1	06	06	.15	9	000	-	-	-
	WASTE LIQUID TANK B26E	●						◉					1	21	42	42	4 5	037			
TEMPERATURE MEASUREMENT AND CONTROL	IR PYROMETER F8E, L20E			●	●	●				●		●	1	.30	.30	.30	9.1	.027	20	20	2000
	LASER PYROMETER F9E, L21E			●	●	●				●		●	1	15	.61	15	11.3	014	200	200	2000
	RESISTANCE THERMOMETER		●	●	●	●	●	●		●	●		**	**	**	**	**	**	-	-	-
	THERMOCOUPLES		●	●	●	●	●	●		●	●	●	**	**	**	**	**	**	-	-	-
	TWO-COLOR PYROMETER F16E, L19E			●	●	●				◉		◉	1	30	30	30	9 1	027	20	20	2000

NOTES

(a) CIRCLED DOTS INDICATE ITEMS USED IN THE CORRESPONDING MINIMUM EQUIPMENT SUBELEMENT.

(b) PEAK POWER IS THE VALUE OVER AND ABOVE SUSTAINED POWER.

(c) FIGURES IMMEDIATELY AFTER THE EQUIPMENT ITEMS PROVIDE A REFERENCE FOR EACH PIECE THE FIRST LETTER REFERS TO THE SUBELEMENT ("B" FOR BIOLOGICAL, ETC), THE DIGITS REFER TO THE NUMBER WITHIN THE SUBELEMENT AND THE LETTER "E" INDICATES AN EQUIPMENT ITEM

*FROM POWER CONDITIONER

**AS REQUIRED

Compiled under "SPACE PROCESSING APPLICATIONS PAYLOAD EQUIPMENT STUDY" performed for George C. Marshall Space Flight Center by TRW Systems Group under Contract No. NAS8-28928. Personnel involved Mr. K. R. Taylor, NASA COR, Mr. R. L. Hammel, Project Manager; Ms. A. Smith, Editor.

FOLDOUT FRAME

			-	20	
			-	100	
			-	100	
			[illegible]00	100	
.46	[illegible]			-	
.22	45.4	.454	-	-	-
.30	45.4	.055	9000*	5000*	-
.30	45.4	.055	9000*	5000*	-
[illegible]	[illegible]	.055	1600*	[illegible]0*	-
[illegible]	[illegible]	.041	300	30[illegible]	-
.15	13.6	.003	3	3	10
.15	2.3	.003	-	5000*	-
.91	362.9	.339	-	6000*	-
.46	68.0	.097	2000*	200*	50
.30	4.5	.027	2000*	200*	10
.15	4.5	.003	- *	2000*	-
.15	1.4	.001	- *	- *	-
.15	4.5	.003	- *	- *	-
.15	15.9	.020	100	25	.20
.61	9.1	.006	50	5	100
.15	4.5	.003	50	50	20
.30	4.5	.041	5000	100-6000	40
.18	.9	.006	-	50*	-
.18	.9	.006	-	50*	-
.03	2.3	.009	100	25	.02
.03	2.3	.000	10	10	.10
.31	90.7	.117	1000	50-1000	20
.15	45.4	.041	200	200	20
.15	11.3	.027	200	200	-
.46	13.6	.041	50	50	-
.21	45.4	.038	200	200	20
.19	9.0	.010	200	20	20
.30	27.0	.027	6000	100-6000	20
.46	40.8	.063	9000	4000	20
.30	16.0	.027	2000	200	30
.15	2.7	.003	250	25	20
.49	13.6	.036	1000	100	-
.15	.9	.002	10	1	02
.30	.5	.000	50	10	02
.30	.5	.000	-	-	-
**	**	**	-	-	-
.05	.45	.000	-	-	-
.15	.0	.000	-	-	-
.42	4.5	.037			
	9.1	.027	20	20	2000
	[illegible]	.014	200	200	2000
		**	-	-	-
		**	-	-	-
	9.1	.027	20	20	2000

[illegible] INC[illegible]RIMENT PREPARATIONS, OPERATIONS AND POST ACTIVITY PLUS INITIAL AND TERMINAL OPERATIONS.

[3] INC[illegible]EXPERIMENT PREPARATIONS, OPERATIONS AND POST ACTIVITY.

[4] CAL[illegible] TOTAL ENERGY PER MISSION' [1] BY THE 'CYCLES PER MISSION'.

[5] CAL[illegible]HE 'TOTAL EXPERIMENT ELAPSED TIME' [3] BY THE 'CYCLES PER MISSION'.

[6] PEAK POWER IS THE DIFFERENCE BETWEEN THE 'AVERAGE POWER' [7] AND THE HIGHEST POWER LEVEL THAT OCCURS WITHIN THE PAYLOAD COMBINATION.

[7] CALCULATED BY DIVIDING THE 'AVERAGE ENERGY PER CYCLE' [4] BY THE 'DURATION PER CYCLE AT AVERAGE POWER' [5].

[8] SUSTAI[illegible] PO[illegible] TYPICAL POWER LEVEL THAT OCCURS DURING THE EXPERIMENT OPERATIONS AND EXCLUDES EXPERIMENT PREPARATIONS AND POST [illegible]VIT[illegible]MES. IT IS CALCULATED BY ADDING THE SUSTAINED ENERGIES OF THE RESPECTIVE SUBELEMENTS AND CORE AND DIVIDING BY THE [illegible] THE [illegible]ERIMENT OPERATIONS TIMES OF THE SUBELEMENTS.

[9] CONSISTS OF THE TOTAL FOR THE EQUIPMENT ITEMS PLUS AN APPROPRIATE FACTOR TO ALLOW FOR SUPPORTING STRUCTURES OR EXTRA SPACE.

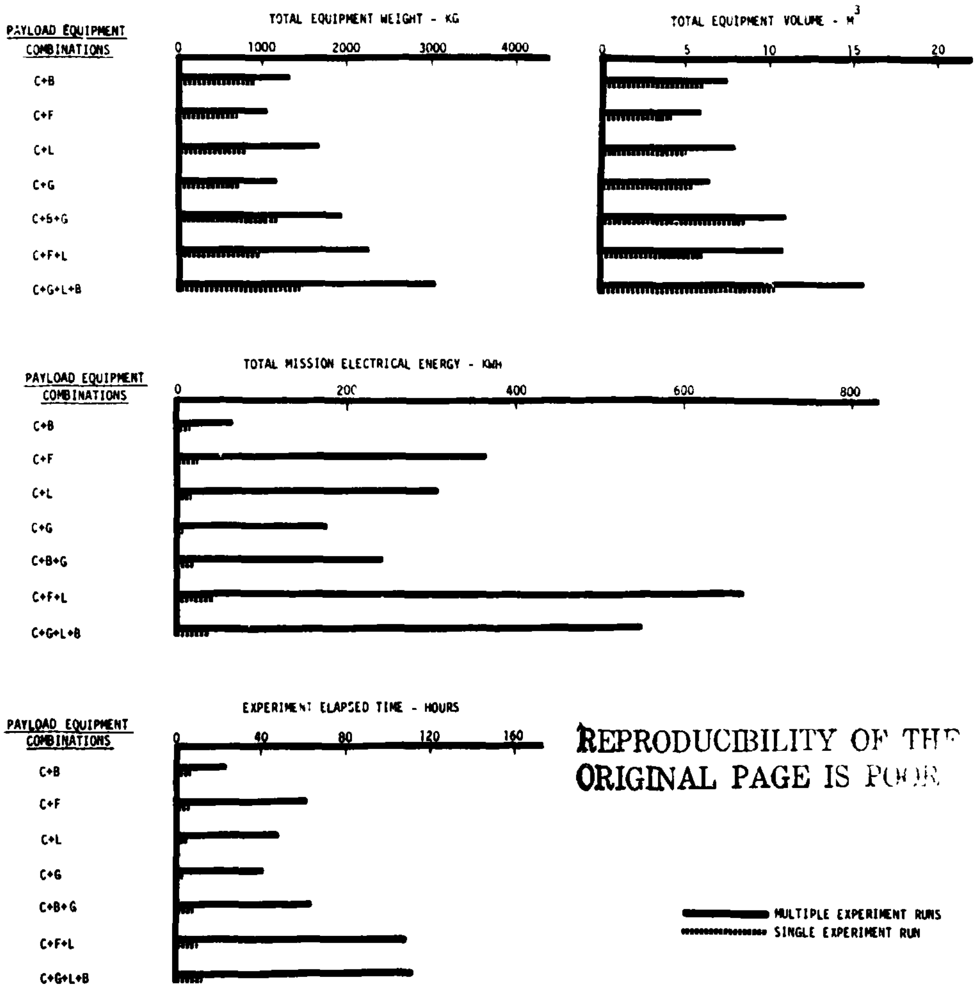
[10] CONTINUOUS.

[11] DEPENDENT UPON PAYLOAD COMBINATION BEING CONSIDERED.

MINIMUM SUBELEMENT DEFINITIONS

L - SEPARATION OF BIOLOGICALS EXPERIMENT
F : IMMISCIBLE SOLIDIFICATION EXPERIMENT
G : RADICAL LIFETIMES EXPERIMENT
1 - GLASS PREPARATION EXPERIMENT

COMPARATIVE ANALYSIS OF SELECTED SPA EQUIPMENT SUBELEMENTS



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