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Westinghouse Astronuclear Laboratory

FUNCTIONAL REQUIREMENTS OF THE NUCLEAR SUBSYSTEM PORTIONS
OF A FLIGHT DATA ACQUISITION SYSTEM FOR NUCLEAR MODULES

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October 1967

FUNCTIONAL REQUIREMENTS OF THE NUCLEAR SUBSYSTEM PORTIONS OF A FLIGHT DATA ACQUISITION SYSTEM FOR NUCLEAR MODULES

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PREFACE

This report was prepared to fulfill the requirement in the CY 1967 Project 2421 work statement to submit a report on the Nuclear Stage Instrumentation System requirements. The Nuclear Stage Instrumentation System was defined in the work statement to include the measuring system, calibration system, telemetry, multiplexers, digital data acquisition system and power supply. It became apparent early in the preparation that to cover the defined scope of the Nuclear Stage Instrumentation System the requirements should be based on the end item and specified mission requirements of a nuclear rocket for manned interplanetary missions; and further, other instrumentation and control systems than the NSS must, to some extent, be included to provide for future integration with these interfaced systems.

Therefore some discussion is included on the interfaced systems for completeness, but it is not intended that the requirements and descriptions in the report alter any previously agreed upon responsibilities for design or fabrication of systems and hardware.

ABSTRACT

A review of the data processing requirements for flight type nuclear modules is presented in this study. The equipment requirements for developmental flight test modules are determined by the analysis of interplanetary mission requirements. The flight data acquisition system equipment must be proven in early nuclear module ground tests. A system design is proposed satisfying the information requirements of the astronauts and earth monitoring stations based upon nuclear module measurements and operating requirements. A program for system and hardware development is recommended in parallel with engine development programs. The flow of data for the nuclear sub-system in this report is from the transducer to telemetry.

TABLE OF CONTENTS

		<u>Page</u>
1.	INTRODUCTION-----	1
1.1	General Requirements -----	1
1.2	Environment Considerations-----	4
2.	MEASUREMENT REQUIREMENTS -----	8
2.1	General -----	8
2.2	Status Monitor System -----	8
2.3	Nuclear Module Measurements-----	10
2.4	Signal Requirements -----	11
3.	DIGITAL DATA MULTIPROCESSING SYSTEM -----	22
3.1	General -----	22
3.2	Nuclear Module Data Processing -----	23
3.3	Functional Requirements for the Instrumentation Unit Equipment-----	31
4.	TELEMETRY SYSTEM CONSIDERATIONS-----	43
4.1	General Requirements -----	43
4.2	Transmission System Considerations -----	43
4.3	Data Compression Factors -----	45
5.	POWER SUPPLY CONSIDERATIONS-----	47
6.	PRE-LAUNCH CHECKOUT SYSTEM -----	50
6.1	Checkout Requirements -----	50
6.2	Pre-Launch Checkout System -----	50
6.3	Launch and Orbital Monitor System-----	54
7.	CONCLUSIONS AND RECOMMENDATIONS -----	56
8.	BIBLIOGRAPHY -----	58

LIST OF FIGURES

		<u>Page</u>
Figure 1-1	Astronuclear Planet Orbiting Research Laboratory (APORL) -----	3
Figure 1-2	Equipment Locations Considered in Nuclear Environment Analysis -----	5
Figure 2-1	Digital Demodulating Technique for Carrier Transducers-----	12
Figure 2-2	Resistance Thermometer and Bridge Circuit -----	14
Figure 2-3	Zone Box Configuration -----	15
Figure 2-4	Multiplexer Block Diagram -----	17
Figure 2-5	Programmed Multiplexing System -----	18
Figure 2-6	Multiplexing Digital Signal Conditioning -----	19
Figure 3-1	Instrumentation Unit -----	24
Figure 3-2	Block Diagram-Engine Data Processor -----	26
Figure 3-3	Block Diagram-Instrumentation Unit-----	32
Figure 3-4	Command Module -----	37
Figure 5-1	Block Diagram of Primary Energy Source and Stage Batteries -----	49
Figure 6-1	Pre-Launch Checkout -----	51
Figure 6-2	Block Diagram for Ground Checkout -----	52
Figure 6-3	Instrumentation Block Diagram for Earth Orbit -----	55

LIST OF TABLES

		<u>Page</u>
Table 1	Expected Environments - 20 Minute Run Time-----	6
Table 2	Monitored Channels During "Coasting" -----	9
Table 3	In-flight Measurements (Per Module) -----	11
Table 4	Permanent Memory Storage -----	34

1. INTRODUCTION

1.1 GENERAL REQUIREMENTS

Certain criteria pertinent to flight systems for nuclear rocket instrumentation are to be developed toward the ultimate application in manned interplanetary missions. Initial utilization of the equipment will be in developmental flight testing of nuclear rocket systems suborbitally or in outer space. The equipment developed for such applications must be adaptable to long range missions. The developmental phase testing of nuclear rocket systems will serve to provide reliability data on the instrumentation systems as well as on the nuclear propulsion system proper. It should be obvious from this that the confidence level in the instrumentation system must be well established prior to initial flight testing of nuclear rocket systems.

A review of the manned mission applications of nuclear rocket systems is essential to determine the instrumentation system requirements. The basic interplanetary vehicle will be assembled in earth orbit from modular components boosted into orbit by Saturn V rocket systems.

Three nuclear stages are required for major propulsion tasks as follows:

- 1) Launch from earth orbit to interplanetary course orbit (three complete nuclear modules).
- 2) Retro-braking into planetary orbit (one nuclear module).
- 3) Launch from planetary orbit to earth return orbit (one nuclear module).

The projected timing for these operations calls for a minimum time span of one to three years from earth launch to launch from planetary orbit. This fact helps to establish the reliability requirement for the nuclear rocket systems. Although this report covers primarily the requirements of the Nuclear Sub-system (NSS), some discussion is given to interfacing other systems, to clarify the operation of the complete system.

The vehicle for launch from earth orbit consists of an assembly of three nuclear rocket modules including engines and subsystems. The complete vehicle therefore will have five nuclear rocket systems. Figure 1-1 shows one concept of a Mars vehicle.

The placement in earth orbit of the five nuclear rocket system components will require five Saturn V launchings to complete the nuclear propulsion assembly with two additional launches for payload and assembly requirements.

These factors suggest the following considerations in the design of the nuclear rocket instrumentation systems:

- 1) Power consumption required for continuous monitoring of all systems for the time involved is excessive from the standpoint of weight and reliability.
(This factor is based upon the premise that standby systems are less prone to failure than operating ones.)
- 2) A maximum amount of equipment must be ejected with each stage such that payload weight may be a maximum.
- 3) The above factors, in conjunction with independent launching of propulsion modules, dictate a maximum of completeness in the instrumentation of each module.
- 4) Ground checkout equipment must be capable of insuring proper functioning of all systems on each module prior to launch.
- 5) Power consumption, weight, and reliability considerations suggest a priority-and-demand control of sampling of measurement data. Measurements may thus fall into the following categories:
 - a) System readiness monitoring for vehicle and telemetry.
 - b) Periodic and/or demand system checkout measurements.
 - c) Pre-start countdown measurements including checkout testing.
 - d) Engine run measurements.

- 6) Since the final operating vehicle is finally assembled in earth orbit, on board checkout capability is a mandatory requirement. All systems must be capable of remote telemetry or local operator control to provide for mission flexibility in the final nuclear rocket systems.
- 7) Instrumentation systems must be capable of long term reliable operation under conditions imposed by launching, and operation in outer space and nuclear-environment-imposed space. Operation in the vacuum of space requires an environmental control system of highest reliability for the instrumentation electronics systems.
- 8) Long-term mission requirements dictate use of redundant multi-processing systems capable of sustaining operation after component failure via selection and rejection processes. These systems must compress and present summary data to the operator or telemetry system as requested. The system must give readiness and problem identification information from about 3,000 sources to operators in non-arbitrary terms.

1.2 ENVIRONMENT CONSIDERATIONS

Some consideration must be given in developing instrumentation systems for nuclear rocket modules to the additional environmental factor imposed by the nuclear engine. Present data available must be regarded as very preliminary; however, review of this information helps to delineate system requirements.

1.2.1 Nuclear Considerations

The principle area of concern for location of telemetry and similar electronic equipment is the area immediately forward of the propellant tank (Figure 1-2). In the operation of the engine, this area is shielded by the hydrogen propellant. This shielding is reduced with engine run time as the propellant is exhausted. Radiation levels and integrated dosages on electronics are largely determined in the last few minutes of full power operation. With the

FIGURE 1-2

EQUIPMENT LOCATIONS CONSIDERED IN NUCLEAR ENVIRONMENT ANALYSIS

possible exception of gamma dosage, the environment seen forward from the top of the propellant tank would be fairly constant with varying mission run times (assuming propellant equivalent to run time plus 3,000 pounds for mission run times of 10 to 25 minutes).

A summary of the nuclear environment expected in the proposed equipment area above the propellant tanks for a 20 minute run time is given in Table 1.

Table 1 - Expected Environments - 20 Minute Run Time**

	INITIAL RATE		FINAL RATE		DOSE	
	R/hr	N/cm ² /sec	R/hr	N/cm ² /sec	R x 1000	nvt.
First Stage	12000	Nil	4×10^6	9×10^{10}	72	1.5×10^{11}
Second Stage	4000	Nil	1.2×10^6	3×10^{10}	24	5×10^{10}
*Third Stage	1200	Nil	4×10^5	10×10^{10}	8	1.7×10^{10}

A brief review of Table 1 indicates that the integrated dosages should be within operating limits for semiconductors. The high dose rates toward the end of engine operation however will require care in electronic equipment design to assure operation under the conditions imposed. Of primary concern would be the photo currents induced by high dose rates, particularly in active semiconductor components.

The nuclear modules themselves may or may not include additional shadow shielding provisions depending upon the mission and other factors. It is expected that the additional shielding would be used on the upper third stage in all cases to afford sufficient payload and crew protection.

The nuclear environment at locations other than the proposed equipment area would generally require a high level of hardening, except along the outside wall of the module, where hydrogen shielding is afforded. This area is generally unprotected and affords little more than space for routing of instrumentation and control cabling.

* Includes shadow shield.

**Based on propellant tanks 70 feet in length.

Some radiation-hardened instrumentation equipment might be located between the engine and the propellant tank. Transducers and other similarly located equipment would be subject to the following approximate environments:

First Stage 10^{11} to 10^{12} N/cm²/sec, 5×10^7 to 10^7 R/hr
Upper Stages 3×10^{10} to 10^{12} N/cm²/sec, 2×10^6 to 5×10^7 R/hr

These levels and the integrated dosage over proposed run times preclude the use of most organic materials. Semiconductor electronic components could not be expected to operate. Cabling and instrumentation components in this area must be regarded with the same caution as that reserved for the engine components.

The contribution of the Van Allen belt irradiation, solar storms and cosmic irradiation should not pose any significant additional burden on the instrumentation systems since these total effects, even for long missions, are several orders of magnitude less than those imposed by the nuclear rocket module.

Figure 1-2 shows the equipment locations considered in the nuclear environment analysis.

1.2.2 Other Considerations

In addition to the nuclear environment, additional consideration must be given to the operation of equipment in a vacuum environment. A form of heat conduction or convection system must be incorporated to dissipate heat from operating electronics. Various equipment could be heat-sinked to the outer skin while others may have to be cooled in a controlled environment. All data system equipment must withstand environments of temperature, humidity, vibration, shock, altitude, acceleration, etc. of a long term flight.

2. MEASUREMENT REQUIREMENTS

2.1 GENERAL

Various measurements will be required to monitor the status of the nuclear module.

Each engine will have its own data system. This will permit checkout on the ground, during launching, and checkout in assembly orbit. All engines will be compatible with the same support equipment. Design flexibility will allow for solutions to problem areas which could arise. Common subsystems will be modularized to optimize system capability, and to facilitate servicing.

Final checkout will be conducted by the on-board checkout equipment. All systems will be verified for proper operation and readiness for launch.

The instrumentation system will be capable of being functionally checked by remote, automatic means during earth orbit assembly of the vehicle. All data available will be transmitted via telemetry to automatic data handling equipment on the ground. The number of data channels subsequently discussed represent the measurements on a per module basis and would have to be multiplied by the number of modules required for a given configuration.

Measurement blocks shall be assigned for the following purposes:

- 1) Continuous monitoring
- 2) Monitoring and checkout during flight (periodic readiness).
- 3) Monitoring performance during powered flight.

2.2 STATUS MONITOR SYSTEM

During a mission, such as a trip to Mars, it is not practical to keep the data system operating on a full time basis. Various channels should be monitored on a periodic basis while other data channels require continuous sampling. Approximately 151 channels of data must be monitored continuously during the "coasting" period. These are summarized in Table 2.

Table 2 - Monitored Channels During "Coasting"

1)	Engine Source Power	3
2)	Temperatures	20
3)	Vibration/Accelerations	11
4)	Displacement	3
5)	Positions	20
6)	Pneumatic Supply Tank	3
7)	Voltage Measurements	3
8)	Propellant Pressure	4
9)	Leak Detectors	40
10)	Propellant Level	6
11)	Strain	5
12)	Propellant Boiloff	10
13)	DAS Environment	15
14)	Neutronics	<u>3</u>
TOTAL		151

The number of measurements requiring continuous monitoring represents about 25 per cent of the total measurements. Frequency response of the continuously monitored channels need not exceed about 10 Hertz. To conserve transmission power, only out-of-tolerance measurements need to be telemetered back to earth.

Those measurements assigned to continuous monitoring will be part of the emergency detection system which warns the astronauts that an action may be required because of some failure in the vehicle. These measurements will be selected on the basis of a failure-effect analysis which delineates the sequence of events that follows a failure. Only a relatively few failures can abort the mission or cause a catastrophe; therefore, reasonable

protection can be afforded by monitoring only a small number of parameters. Transducers monitored shall be categorized for either "manual" or "automatic" abort. The "manual" abort signals will be routed from the engine stage to the spacecraft control room for visual display. The "automatic" abort measurements are those which indicate a catastrophe has occurred or will occur in less time than a human could react. These signals are sent to the vehicle safety systems. Care must be taken to insure the reliability of the transducers used in the emergency detection system. Redundancy and voting techniques will be utilized to guard against both failures in indicating circuitry and false indications. These measurements will be transmitted from the vehicle control room telemetry system after processing.

2.3 NUCLEAR MODULE MEASUREMENTS

Table 3 presents a list of measurements necessary for the flight module of the nuclear engine during operation. The numbers and measurements are derived from the preliminary Flight Test NERVA Engine Measurements Requirements Document NE-8 and 10. In addition, the table includes measurements which must be made on the propellant tank system and data acquisition system environment.

Approximately 40% of all signals will be from transducers having low level outputs. Some measurements associated with the control system are sent to average/reject circuits which will minimize the number of data channels necessary for processing.

Wide band data (such as acoustics and vibration) will be routed to swept-filter spectrum analyzers to conserve transmission bandwidth. The output of the processing system will be transmitted by pulse code modulation-phase modulation (PCM/PM). Depending on frequency and accuracy requirements, it may be required that an additional frequency modulation-frequency modulation (FM/FM) or single side band-frequency modulation (SS/FM) system be utilized.

2.4 SIGNAL REQUIREMENTS

The outputs of all transducers must be adapted to the telemetry input requirements. Various types of conditioning equipment may be used.

Table 3 - In-flight Measurements (Per Module)

Measurement	Number
Pressure	33
Temperature	82
Events	103
Position & Displacement	45
Voltage & Current	16
Speed (RPM)	3
Vibration & Acceleration	47
Neutronics	3
Processed Analog	10
Control Analog Command	6
Binary Command	76
Individual Analog Command	21
Leak Detectors	40
Propellant Mass/Level	6
Propellant Tank Pressure	4
Angular Velocity	3
Acoustic	3
Strain	20

Table 3 (Continued)

Measurement	Number
Propellant Tank Boiloff	10
Flow	3
Misc. (DAS Environment)	15
TOTAL	549

2.4.1 Variable Reluctance Transducer

Radiation hardening considerations could dictate the use of variable reluctance transducers moreso than in conventional engine systems. Outputs from variable reluctance transducers requiring AC excitation could be conditioned utilizing digital techniques. The excitation frequency can be derived from the digital data system and conditioned to a sine wave for the transducer carrier. A synchronizing signal could be generated at the zero-crossing point of the reference signal. This synchronizing signal would enter a preset delay circuit which would deliver an output delayed by the inherent phase shift in the system plus a predetermined amount to allow the output signal to the data system to be the average of the signal. A block diagram of this system is given in Figure 2-1. The output of the delay circuit is routed to a sample-and-hold circuit. The frequency response of this technique can be as high as about one-half the carrier frequency depending upon the measurement requirement.

Figure 2-1 - Digital Demodulating Technique for Carrier Transducers

2.4.2 Vibration and Acoustic Data

Vibration and acoustic data would be handled by a spectrum analyzer to conserve on frequency bandwidth and telemetry transmission power. The information (root power spectral density) extracted by the analyzer varies at a much slower rate than the input signals. Thus, output signal frequencies of the analyzer channels are lower than those of the input signals. In this technique a swept local oscillator signal is mixed with each incoming signal. Difference components are examined, and the AC signal produced is rectified and then averaged. These averaged output signals (one for each channel) are the fourth root of the power spectral density for each input signal. Calibration is accomplished by means of two marker signals. The first occurs at zero frequency (DC) and the second operates above the maximum data frequency. It is generated by a calibration oscillator that is stable in amplitude, thus providing for amplitude calibration. Output signals are balanced and isolated from each other and from the inputs. Adjustable sweep rates would be incorporated for broader application. Follower amplifiers should be required for piezoelectric accelerometers as impedance matching devices for the swept analyzers.

2.4.3 Temperature

Basically, two types of temperature sensors are used on the nuclear module; thermocouples and resistance thermometers. Resistance thermometers consist of a continuous wire grid, the size, length and composition of which depends upon the desired measuring range. The active element has a positive temperature coefficient of resistance. The resistance thermometer is usually incorporated as one leg of a full bridge circuit.

A thermocouple is a two-wire, two-junction sensor. Each junction is made of two dissimilar wires. When a temperature difference exists between the two junctions, a voltage is generated which is proportional to the temperature difference. The composition of the junction wires determines the measurable temperature range. The various types used on a nuclear module would be copper-constantan, chromel/alumel and tungsten/tungsten-rhenium. To obtain accurate temperature measurements, the reference junction must be kept at a known constant temperature. Maintaining this constant reference temperature for in-flight measurements is impractical; as a result, zone boxes should be used in conjunction with all

thermocouples. Tungsten/tungsten-rhenium thermocouples do not need to be referenced. Their error is insignificant compared to the range of the measurement. Typical block diagrams are given for the types of sensors used.

Figure 2-2 - Resistance Thermometer and Bridge Circuit

A typical zone box configuration is shown below. The zone box contains the reference junction which is in thermal contact with the compensating resistance thermometer. Since the resistance thermometer controls the resistance of one leg of the bridge, the output of the bridge circuit will follow the temperature induced voltage of the hot junction. The bridge is so calibrated that it will cancel any voltage produced by the reference junction as a result of an increase or decrease in temperature.

Figure 2-3 - Zone Box Configuration

2.4.4 Signal Conditioning

The outputs of all transducers must be adjusted in range for input to the data processing system. Typically, two or three signal levels may reasonably be accommodated in this higher order system. Recent advances in multiplexers have permitted them to assume an increasing number of the functions formerly performed by signal conditioners. Systems are proposed herein which may eliminate signal conditioners as a separate component. To achieve this end, transducers are processed through multiplexers in similar groups, and with varying requirements.

Transducers may require one or more of the following functions to interface with data processing systems:

- 1) Zero Suppression
- 2) Full Scale Ranging
- 3) Excitation
- 4) Demodulation
- 5) Junction Referencing

Transducers range from thermocouples with universal calibrations to those requiring individual calibration curves. Thermocouples are non-linear devices requiring tabulations to secure engineering units. The balance of the transducer types are linear devices (within acceptable limits) with varying offset and sensitivity requirements.

By grouping the transducers of similar types and/or conditioning requirements and using multiplexer switching, uniform outputs can be presented to the higher order processing system. Synchronous timing must be provided.

The simplest multiplexer signal conditioning system is that which is possible if transducers have common ranges and common zero suppression. In this case, this group of transducers can be handled with a multiplexer arrangement offering fixed gain and zero reference. Thermocouples are examples within this category. In the nuclear subsystem three types of thermocouples are used, covering about 10 different ranges. These signals could provide a correctly ranged PAM pulse output with the equipment shown in Figure 2-4. Identically ranged input signals are applied to each multiplexer switching unit, along with a reference voltage for test purposes. Fixed zero suppression and fixed amplifier gain provide the required signal output to the analog-to-digital (A-D) converter. The A-D converter provides an eight-bit word coding for each PAM sample.

The more difficult signal conditioning problem, involving individual transducer calibration characteristics may be handled in two different methods depicted in Figures 2-5 and 2-6. The best method may be determined by further detailed study of the module data acquisition system, which contains some computation capability.

To achieve signal conditioning within the multiplexer, the equipment arrangement of Figure 2-5 is required. The arrangement is similar to that offered in Figure 2-4 except for the addition of sequential programming of zero suppression range. Again, the ranging would be limited by selection of similar transducers. Programming of $\pm 50\%$ on range and zero suppression determined by an eight-bit permanent memory [(NDRO) non-destructive readout] records for each parameter may be utilized. These memories would be programmed prior to launch from individual transducer calibration sheets. The respective memory data

Figure 2-4. Multiplexer Block Diagram

Figure 2-6. Multiplexing Digital Signal Conditioning

would be gated to adjust the gain and zero offset of the multiplexer in step with transducer sampling. In this manner mixed transducer inputs can be handled with uniform PAM output.

The above basic system can, with gating-controlled sample-and-hold amplifiers, perform demodulation as described earlier. The only limitation is that signal frequencies must be low when compared with the carrier frequency.

The alternate method for handling intermixed transducers is illustrated in Figure 2-6. Here, $\pm 50\%$ over-ranging in range or zero offset can be handled with a minimum of equipment. (It may be noted that greater range is possible by either technique with consequent increase in equipment accuracy to achieve the necessary resolution.) Sampling is done with fixed and zero reference and is followed by an A-D conversion with increased resolution (nine bit minimum). Zeroing and ranging are now accomplished on the digitized sampling in a manner similar to the previous operation. The computer is programmed to add to achieve zero correction and to multiply to achieve range correction using sequentially-gated memory data. All computations can be performed using a simple adder. The output would be the eight-bit most significant data, compatible with the higher order system requirements. Computations can be readily achieved in a one sample time.

Several advantages can be realized from adoption of these signal conditioning methods:

- 1) Reduced power consumption and weight are achieved.
- 2) Redundant signal conditioning is made possible.
- 3) Adjustments and mating problems with transducer and signal conditioning are eliminated in favor of programming.
- 4) System flexibility is increased.

It is obvious that the signal conditioning concepts outlined herein could be expanded to handle all narrow band channels in a single piece of equipment, containing built-in redundancy. Long term stability can be achieved through commutated AC amplification; the number of active devices in the system may be reduced by this technique. Further, the utilization of active devices in a switching mode increases their failure margin.

Some of the principles proposed herein are in use in ground systems employing general purpose computers. Tailoring these systems to space applications requires detailed study of the reliability, power, weight and other advantages which may be realized on a complete system basis.

The above considerations along with modular servicing requirements of long time missions, suggest the development of programmable multiplexers in interplanetary vehicles. Their application should provide the necessary flexibility required for redundancy and modular buildup of complex systems.

The selection of the best system for flight equipment requires further study. A more detailed analysis of the added computation requirements versus conventional signal conditioning is required.

2.4.5 Distribution Center

All signals from the nuclear module should be connected to the distribution center where all signals may be directed to pre-assigned channels in the data acquisition system.

3. DIGITAL DATA MULTIPROCESSING SYSTEM

3.1 GENERAL

3.1.1 Introduction

An on-board data processing telemetry system (DPTS) designed for in-flight maintenance, experiment verification and astronaut verification during an extended manned mission is described. In all cases maximum reliability, flexibility and low power requirements primarily dictate the methods used in accomplishing the designed objectives. The DPTS system will provide capability to: 1) perform flight checkout at various stages of spacecraft activity from ground launch to mission completion; 2) perform diagnostic testing for any of the spacecraft engine subsystems; 3) control and manage data for experiments; 4) receive and verify commands to the vehicle; 5) monitor and confidence check any desired data channel; 6) confidence check any data processing subsystem; 7) reconfigure the data flow when either equipment failure or mission phase changes.

3.1.2 Design Constraints

System design factors are influenced by the following factors: 1) Space and Weight - The hardware and energy necessary to perform a computation are held to a minimum. In many cases payload weights are increased by accommodating the instrumentation in the lower stages. 2) Flexibility - Possible malfunctions make it necessary to rapidly shift measurements to automatically locate anomalies. 3) Reliability - Only flight-proven techniques and hardware are considered. 4) Multi-processing Techniques - In addition to providing high system reliability, flexibility and low power requirements, these systems provide identical data and control processes for each nuclear engine. Each DPTS system (one for each engine) will remain dormant until called into the active state via ground telemetry or astronaut command. 5) Automatic Checkout - Because of the long periods between assembly and flight, verification is made that all systems are functioning properly and are in a ready-to-launch condition. If a malfunction has occurred, it is to be located at a subsystem or source level. These requirements increase the number of points to be monitored and the amount of data to be observed and digested before proceeding with the launch.

3.2 NUCLEAR MODULE DATA PROCESSING

3.2.1 General

Supporting long-term manned missions results in an enormous array of experiments, some of which must be performed and digested in real time. Very specialized tasks are imposed on the data processors. As a result, a redundant, compact multi-purpose data processor is employed. It offers the features of high reliability, flexibility, and high system throughput. These advantages are obtained by using multi-processing techniques, i.e. a large number of identical, simple processing units which can be operated either independently or simultaneously.

Because of the highly parallel nature, this particular system concept can tolerate slow speed individual processing units and yet still maintain high overall system throughput. This characteristic relaxes the speed requirements of the hardware design, increasing reliability considerably. Being able to switch individual processing units in and out of the processing pool (as determined by self-checking schemes) allows for flexibility and ease of system reconfiguration. When a hardware error is detected, the responsible faulty processor unit may be paralleled or substituted with another identical unit; as a result, the faulty data channel will be bypassed. Such a system configuration would degrade slowly rather than fail catastrophically, increasing the probability of overall mission success.

3.2.2 Generalized Block Diagram

Figure 3-1 illustrates the entire data acquisition system for the three stage manned Mars mission. Shown are five identical data acquisition systems (one per nuclear engine) and one central control unit defined as the primary data processor. Each data acquisition system has the capability of accepting engineering data from approximately 600 analog signals of 10 Hertz bandwidth. This information is time multiplexed into a predetermined sequence, and each sample of this sequence is converted to a 7-bit-plus-sign binary word. The acquisition system will also accept digital data from other sources or command subsystems and time multiplex this with the engineering data. The resulting data are stored, checked for limits, then prepared for transmission to the ground.

* Transmitters for Stage 2 & 3 modules in special launch nose cone for use prior to vehicle assembly in orbit.

The primary data processor is assigned the chore of buffering compressed data from each of the acquisition systems; after applying data compression, the usable information is formatted and conditioned for eventual transmission to the ground station. The primary data processor will also provide two other necessary functions: 1) Search Operations - In this programmed condition the processor will provide routines for checking equality, inequality, or limits for any of the stored data; 2) Processing Operations - In this mode computations are performed to simulate any of the engine control subsystems or to perform averaging techniques of the data.

3.2.3 Data Acquisition Block Diagram

Figure 3-2 illustrates the functions performed by the module data acquisition system. Commands are received by either ground or astronaut for use in controlling spacecraft thrust, conducting experiments, and transmitting experiment and spacecraft status data to astronaut and ground tracking stations. The data acquisition system is a digital processing and memory element which performs the following functions with respect to these commands:

- 1) Verifies the accuracy of commands transmitted from the ground tracking stations.
- 2) Stores commands in its memory from ground or astronaut for subsequent use.
- 3) Executes commands either in real time or delayed mode.
- 4) Provides swept filter data compression.
- 5) Prepares stored data for transmission to ground or astronaut.

In Figure 3-2 the dotted subsystems are provided for use only in the first stage. For stages two and three the main telemetry system and command receiver (located within the Instrumentation Unit) are used.

3.2.4 Data Acquisition Logical Organization

Shown in Figure 3-2 is a detailed block diagram of the data acquisition system. Operation of the system will be discussed in terms of system clock, command verification, command storage, command excitation, data flow reconfiguration, and data preparation and formatting.

Figure 3-2 Block Diagram
Engine Data Processor

3.2.5 System Clock

A highly precise and reliable crystal controlled oscillator synchronized from the higher order Instrumentation Unit (IU) system, supplies the fundamental clock frequency. A shaper-driver circuit shapes this signal and transfers the resultant waveform to a frequency divider. From this divider are derived clock pulses and bit gates used in executing real or delayed mode commands.

3.2.6 Command Verification and Storage

Commands transmitted to the first stage from the ground are routed from the command receiver to the Command Decoder and Distributor, where the commands are synchronized and verified for use by the command input logic. Commands are also echoed back to ground, via the Data Formatter and spacecraft transmitters, for further verification.

To accomplish the verification, as well as to prepare a valid command, it is necessary to synchronize the command message with the basic timing system. Command verification is accomplished by storing the first command word as it is received. This word is then compared bit-by-bit with the succeeding incoming identical command verification word. If a successful comparison is made, the command will be executed. If an error is detected in the command signal, the Data Formatter will immediately generate a unique error-burst word which will be transmitted back to ground until a new command is properly verified.

3.2.7 Command Execution

A large number of discrete commands are used to control the data acquisition process. These commands may be executed immediately or in a delayed mode at a time previously programmed. Command execution is a result of a number of discrete command control signals synchronized to the system timing to control the data handling process or flow within the acquisition system.

Priority control execution is determined by the Command Decoder and Distributor. If a particular part fails, the highest priority is assigned to a command to reorganize the data flow.

3.2.8 Automatic Checkout of Multiprocessors

The automatic calibration system enables a remote checkout of the flight instrumentation system and associated equipment to insure functional readiness and operation of the vehicle engine. When a hardware error is detected, the responsible faulty processing unit will be switched off and the system will reconfigure automatically. The format for reconfiguration could also be changed to maximize the transmission of useful data if engine malfunctions were detected.

3.2.9 Data Flow Reconfiguration

Reliability and flexibility of the new generation data processors will not be gained primarily from the application of new and more reliable electronic devices, but rather through system orientation. The modular multiprocessor is an example of such an organization. With this configuration the data flow process is totally parallel and can be configured and reconfigured as conditions command. Extreme reliabilities can be achieved in this manner of organization.

3.2.10 Priority Data

Output data from the signal conditioners are rated with priorities ranging from 1 (most redundancy) through 4 (least redundancy). Priority 1 data are handled by all four multiplexers, priority 2 data by two units, priority 3 and 4 by one unit each. With this data channel input configuration, active processing units are held to a minimum. When full processing capabilities are needed, all four multiplexers are active; in the normal mode, multiplexer 1 provides the required transfer of data.

3.2.11 Multiplexer

After the transducer signals have been conditioned, they must be routed to the proper telemeters. The analog information is processed first through eight time division multiplexers. They are high and low level units, operating from one synchronized four-phase control clock. Using this means of control (each high-level multiplexer operates from one phase of the control clock), multiplexers 1 through 4 can be operated independently or in any group. When full data processing is needed (i.e. full power), all four multiplexers can function. When minimum processing is required, multiplexer 1 may be a sufficient sampler.

For the low-level multiplexing scheme, control processes are identical in nature to those controlling the high-level operation.

3.2.12 Scanner

The output of each time division multiplexer is connected to a scanner input. Each scanner block is an analog voltage gate which allows the measurement voltage sample to pass through the gate when the gate's associated timing logic comes true. The output of the scanner section contains all the data channel information in interlaced form.

3.2.13 Analog-to-Digital Converter

The analog-to-digital converter section accurately changes interlaced voltage samples into coded digital representations. Either converter can accept and convert (to 7 bits plus sign) information produced by the multiplexer section operating at full load. Speed of the converter is relatively moderate. Under full load conditions, data requirements dictate a converter capable of performing sampling rates in the order of 30,000 to 50,000 samples/second (assuming a maximum of 10 Hz variation of data and the necessary redundancy of priority channels).

3.2.14 Data Handling and Storage

Due to the parallel processing capability novel input/output techniques are used to provide genuine parallel access to the memory. Information from two analog-to-digital converters, digital sensor outputs, data timing and identification are manipulated for entry into data storage. Reliability and power requirements dictate the use of a non-destructive memory that would retain its contents in event of power interruption and not consume excessive power during repetitive transmission to ground.

3.2.15 Error Detection

The error detection system provides real-time source malfunction indications to the astronaut by means of the IU system when data resulting from the processing subsystems fall from the prescribed tolerance band; in addition, the out-of-tolerance value is stored, formatted, and transmitted along with information flagging that it is in error to ground tracking stations for "immediate" indication and further processing. Using this data compression technique a reduction of telecommunications bandwidth is achieved. Data processed through normal channels can be transmitted at lower rates; anomalies are transmitted in real time.

The basic error detection consists of the three (3) major components. They are a predictor, a comparator, and a buffer. The predictor anticipates the value of the next sample on the basis of previous knowledge of the data characteristics. The comparator tests the incoming sample against this predicted value. A tolerance band or "aperture" defining the allowable prediction error will be previously determined in accordance with accuracy requirements. If the actual data sample falls within the same aperture in which the predicted value lies, the sample is judged to contain no useful information and is transferred to the next higher order system. However, if the new sample falls outside this aperture, an error signal is generated for subsequent transmission over the data link. The error information and data samples chosen by the comparator for transmission will be sent to the data formatter at some irregular rate. This buffer, located in the core memory will hold this sampled signal until the time it will be transmitted.

3.2.16 Data Formatter

The data formatting is performed in an encoder which is to accept the compressed spacecraft measurement data in the form of digital information, convert the data to an optimum serial code, modulate a subcarrier with the coded binary data, and add synchronization information, thus forming a signal to be presented to the telemetry transmitter.

To obtain bit and word synchronization for telemetry a cyclic pseudo-random code is used. This code, generated by a pseudo-random code generator, is synchronized with data and synchronization subcarriers. Bit and word synchronization are derived through a series of gates which generate pulses that synchronize the commutator, analog-to-digital converters, and all digital data inputs.

To provide bit and word synchronization to the ground decommutators, the pseudo-random code can be phase modulated onto the synchronization subcarrier. The ground demodulator can generate a local pseudo-random code, identical to the code transmitted to ground, and step the two codes past each other until both are in phase. Word gates like those within the acquisition system form accurate word and bit synchronization pulses with which to drive the decommutation sequence.

3.3 FUNCTIONAL REQUIREMENTS FOR THE INSTRUMENTATION UNIT EQUIPMENT

3.3.1 General

The data acquisition equipment on the nuclear modules must be further supplemented by higher order systems in the Instrumentation Unit (IU) of the nuclear vehicle. The IU systems must control module data acquisition systems and serve maintenance and monitoring functions for the use of the astronauts. They must also reduce long-range telemetry power requirements by means of additional data compression. The following summarize the basic requirements which must be satisfied by the IU data system equipment:

- 1) Provide condensed status reports in engineering units to the astronauts and earth monitors via telemetry.
- 2) Provide command input by the astronaut and earth telemetry via a priority interrupt system to determine its own as well as module subsystem operations.
- 3) Provide categorized malfunction warnings to astronaut and earth monitors for maintenance planning and alarm purposes.
- 4) Provide complete on-board checkout capability for all nuclear modules for periodic checks and countdown control, preceding stage operation.
- 5) Provide real time data compression utilizing averaging and prediction techniques to optimize long-range telemetry power and bandwidth usage.

It is obvious that the above requirements may only be handled by a digital computer system. The recommended system (considering the reliability requirements) would utilize two computers with check problem switching control to assure continuity of operation during the critical operate periods (Figure 3-3).

Computers of the type required for this task are presently available from a number of sources; they are light in weight and have low power consumption (approximately 20 pounds and 150 watts at present, with significant reductions in both expected in time for this application).

The input data being transmitted from the individual nuclear modules to the Instrumentation Unit equipment will depend upon the operating mode of the module and the priority

FIGURE 3-3
 BLOCK DIAGRAM
 INSTRUMENTATION UNIT

of the data. Modules being used for propulsion would be the prime source of data input; data for monitoring would be taken only from the inactive stages. Data from the operating modules will be further rated according to priority of importance to the astronaut and automatic operation. Such assignment of priority is designed to reduce the computational work load of the computer system. In addition to these data, the module data acquisition system will furnish malfunction data to the IU equipment to eliminate the associated erroneous data from the computation processes.

The computation will involve a number of permanent programs which must be fixed prior to launch. These would include the following:

- 1) Programs for operation of each stage of the vehicle (1 through 3) outlining input and output assignments.
- 2) Programs for in-flight checkout of the modules and vehicle configuration.
- 3) Programs for malfunction and alarm computation for various flight and monitor requirements.
- 4) Programs for telemetry data assignments associated with the various monitor and operate modes.

The astronaut or ground control systems may utilize all or part of the fixed programs as the situation permits. In addition, some provision may be contemplated for additional program inputs by the astronaut for conducting experiments or maintenance tests. Such details may evolve in future studies of mission requirements.

Certain memory storages must be utilized for implementing the programs. These stored references would serve as criteria for determining final malfunction analysis in all modes of operation. This memory size is maintained at a reasonable limit by using priority and module similarity as limiting factors. During power operation computation will be required to select the memory location of appropriate evaluation criteria.

The memory functions may further be reduced by use of scaling factors in the programs and the tolerances allowed in the parameters. Most of the stored parameters will be used

in all of the programs in determining operating status. Memory parameter information and tolerances required must be well established prior to flight testing or mission application of the nuclear modules.

Table 4 lists the items which must be stored in the permanent memory for the above functions:

TABLE 4 - PERMANENT MEMORY STORAGE

<u>Parameter</u>
1. Drum Torque
2. Drum Position
3. Core Temperatures
4. Actuator Gas Storage
5. Propellant Level
6. Propellant Tank Pressure
7. Engine Plenum Pressures
8. Flow
9. Exit Gas Temperature/Chamber Temperature
10. Neutron Power and Period
11. Thrust (or power level)
12. *Acceleration
13. Vibration Limits
14. Strain Limits
15. Gamma Level Limits
16. Number of Redundant Channels
17. Voltage Levels

A number of the above parameters must be in the form of linear equations or tables for utilization at changing power levels. During power operation the prediction storage location must be computed based upon thrust computation from temperature and flow measurements.

*To insure hydrogen position on startup and run.

Checkout and monitor functions would be on fixed reference parameters. The redundancy reference data would be used in determining the level of concern on equipment outages.

Data compression on less critical measurements would be on an average, reject and last-measurement-comparison basis. (The latter is a most powerful prediction tool since virtually no change should occur in succeeding measurements at the rates of information flow used. A secondary intent is elimination of communication errors which could occur in data transfer throughout the system.)

3.3.2 Status Reporting to the Astronaut

A variety of techniques for reporting status to the astronaut exists. In the case of interplanetary missions an earth telemetry link from vehicle to astronaut (currently used) is not feasible because of the timing involved. A detailed coverage of equipment or arrangements to be used is beyond the scope of this study. The reporting of alarm conditions on a category of urgency basis will be covered in a subsequent section of this report. The other data required by the astronaut must be in a condensed format compatible with human capacity to make decisions. These must be divided into long-term monitor, countdown, and operation requirements. A long-term log record which might be served by printed or recorded output may be required prior to actual operation. A condensed real time monitoring scheme such as a cathode ray bargraph display may be required.

The final data output to the astronaut, in any event, must be in engineering units. The IU computing equipment must perform this identity and conversion function for the astronaut.

Information to the astronaut must be updated each 1/4 second or oftener. Such processing would not be a significant burden to the computer.

Some recording during engine operation for later evaluation by the astronaut may also be required. Inputs to the navigation system, such as thrust and operation times would probably fall into this category.

The status report given to the astronaut would be invaluable data to earth monitors. For this reason, it is recommended that this output data be telemetered (whenever possible)

to earth tracking stations. Since this information flow rate is low, a relatively low-power telemetry channel could be used. It would have an additional advantage of permitting earth tracking stations to observe the overall operation as seen by the astronaut, using relatively simple equipment.

3.3.3 Command Input System

The command input system is shown in Figure 3-4. The system accepts input from earth telemetry or the astronaut in performing the various duties assigned. Command data is coded information, selecting the appropriate computer programs or sub-programs.

In order to direct commands into the system, a priority system is required to cover the order in which multiple commands must be executed or time-shared. System operational sequencing is based upon this determination.

In the case of earth telemetry commands, a repeat command and execute system must be used to prevent erroneous input. In the case where a long distance (such as a Mars orbit vehicle location) is involved, this link could require 30 minutes to complete a command.. Such transmission times would impose serious limitations under certain circumstances. Thus, on-board computation and decision-making is absolutely necessary.

The command system must be able to utilize portions of programs and systems in order to minimize power consumption and to increase reliability. This can be achieved in the command programming by utilizing equipment and output only as that required to deliver the requested information.

3.3.4 Malfunction Determination and Reporting

Certain out-of-tolerance measured parameters in the standby and engine operation modes will fall into categories from "of interest" to "alarm". The decision as to the importance of the malfunction or out-of-tolerance measurement must be determined by on-board computation for use by the astronaut. For reasons of limiting the size of on-board computers, the items surveyed in this manner must be limited to the more important standby and operate measurements. The data stored in the computer memory (Table 4) would be utilized in this determination.

FIGURE 3-4
COMMAND MODULE

A typical listing of parameters and judgment criteria used by the computer for standby monitoring would be as follows:

	<u>Item Monitored</u>	<u>Measurement Limits</u>
1)	Power Supplies	Voltages and Currents
2)	Environment (equipment)	Temperature
3)	Gas Storage	Pressure
4)	Propellant	Leak Detectors
5)	Propellant	Level
6)	Propellant	Tank Pressure
7)	Source Neutrons	Count Rate
8)	Stress	Strain

During periodic checkouts, countdown and engine operation, the following types of measurements must be tolerance-scanned in addition to those listed for standby:

	<u>Item Monitored</u>	<u>Measurement Limits</u>
1)	Propellant	Flow Rates
2)	Reactor Core	Temperatures
3)	Exit Gas	Pressure and Temperature
4)	Control Drums	Position and Torque
5)	*Nuclear Safety	Gamma Level
6)	Tie Rods	Temperature and Strain
7)	Speed	Drums and Pump
8)	Various	Vibration Levels

These measurements must be supplemented by surveys of all on-board data sources using the error-detection methods to locate defective system components. The computer must compare the defects with operating redundancy and report the problem in the correct category of urgency caused by the defects.

*Minimum propellant level reduces fuel shielding affecting electronics and other systems; sensors at the forward end of modules determine the level of exposure.

Monitoring functions must be performed on non-operating stages at the same time that lower stages are operating. These dormant stages would be more likely to show difficulties during and following lower stage operations than during long coast periods. Monitoring and recording at this stage of operation may be invaluable in determining maintenance requirements.

The status levels of prime interest to the astronaut and earth monitors must be limited to those which are practical and necessary. Most systems are limited to four status levels, generally described as follows:

- 1) A malfunction has occurred, but is not affecting operation.
- 2) A malfunction has occurred, reducing system reliability. (A subsequent failure in the same system will cause shutdown.)
- 3) A malfunction has occurred, necessitating reduced power.
- 4) A shutdown malfunction has occurred.

Unless a malfunction reporting system exists, control action may have corrected system operation without operator knowledge. Such a system alerts the astronaut that operator input to the system is, or may be, required to complete the mission.

The first status level need not alert the operator but should be reported periodically or upon request. Such malfunctions which in themselves do not affect or limit operation, would over long missions, give valuable information on system reliability. Data taken would also serve as a guide for planning maintenance or corrective action in advance of more serious difficulties. Periodic recording for comparison of time histories is recommended for long-term trend determinations.

Like the status report to the astronaut, the malfunction monitoring output would be invaluable to earth monitors. This output may be telemetered at a low data rate, since it is supplemental information; a relatively low power (narrow band) telemetry system can convey this output. The primary use of the data by the earth monitor would be on-line review with the astronaut and also to direct analysis of real-time telemetry data to support the astronauts in deciding corrective actions.

3.3.5 Checkout Operation

Another major function of the IU equipment is that of checkout. The interplanetary vehicle is finally assembled in orbit. It is an initial requirement of this system to complete the vehicle checkout prior to departure from earth orbit. The IU equipment must be able to conduct countdown checkouts of the vehicle in its various staging configurations as well as periodic checkouts to establish time changes or maintenance needs.

The basic operation of the checkout programs would be similar to that associated with the pre-launch checkout. The basic functions of calibration and error detection afforded by the module data acquisition system, and the malfunction analysis system of the IU system would be utilized. In addition, the checkout must include stimulus to the control system with response observation.

The control stimulus and response tolerances would be part of the permanent memory on a single typical module for utilization by the checkout program. Slight variations over the typical module stored data would be incorporated in the checkout program. These would come mostly from ground tests of the individual modules.

The stimulus response program would consist partly of the following:

	<u>Stimulus</u>	<u>Response</u>
1)	*Δ Drum Position	Torque
2)	*Δ Drum Position	Position 24 Drums
3)	*Δ Drum Position	Source Neutron Level
4)	Valves	Position

The checkout would proceed on a per module basis, reporting status to the astronaut and earth monitors via telemetry.

In the case of the first stage, simultaneous stimuli to a single actuator on each of three reactors may be required for checking interrelationships and system balance. Checkout needs of such a tandem arrangement are not sufficiently established at this time; however, it is expected that special tests of the type described will be required.

*One actuator at a time.

3.3.6 Data Compression Function

The weight and power considerations for interplanetary telemetry equipment demand the highest conservation of bandwidth for practical system design. On the other hand, it is important from the cost and safety standpoint that the greatest amount of data be made available to earth monitors for astronaut support.

The basic philosophy for achieving a compromise in telemetry power and assuring sufficient data for earth monitor support is as follows:

- 1) Limit real-time telemetry using data compression techniques (including error channel rejection, averaging, redundancy elimination, spectrum analysis, and prediction).
- 2) Transmit all measurement data at a lower sample rate for support of compressed data.
- 3) Transmit malfunction and condensed status data as presented to the astronauts by the IU computer.

These telemetry design criteria should present the earth monitor with the necessary data for mission support with a minimum payload penalty.

Because the telemetry power problem is not critical on the earth - departure first stage section, supplementary real-time telemetry may be added to these modules. The maximum communication distance of concern would be less than 25,000 miles. Local low power systems would cover the peak data burden imposed by operation of clustered engines. The IU computer load would similarly be reduced to priority data compression and comparison tasks which would be required for clustered stage operations. The use of module-located supplemental telemetry would also be useful on early development test flights of single modules. In this case the additional data would serve to establish confidence in the module as well as in the IU data compression techniques.

It can be readily seen that effective utilization of telemetry equipment throughout an interplanetary mission requires highly flexible equipment. Coding of telemetry frames and synchronization must change to identify the data transmitted under the many operating

and test modes encountered. These modes and the corresponding telemetry coding must be established prior to earth departure and maintained throughout the mission, according to existing IRIG standards. Earth receiving stations must be equipped to recognize the changing data recognition patterns associated with the operating modes. It may be necessary to utilize a separate telemetry channel from the IU command controller to achieve this synchronization. The needs in this regard should be established early in the hardware development program.

The data compression computations in the IU equipment would be programmed as follows:

- 1) Data from the module data acquisition system along with out-of-tolerance and malfunction information would be routed to temporary storage.
- 2) Data deemed valid at the module would be compared with last average and accepted or rejected for average computation.
- 3) Average would be compared with computed predictions if priority dictates that a tolerance check is required.
- 4) Compressed data are sent to the real-time telemetry channel via temporary storage. Malfunction data, as determined by prediction and redundant channel averages, are sent to memory storage.
- 5) Periodic computation of condensed status output and malfunction alarm categories are presented to the astronaut and telemetry.

The data flow into the IU computer(s) will be at a rate of approximately 12,000 words per second. The principle operations on the data will be averaging and comparison. Existing computers can handle 200,000 additions per second, multiplication at 25,000 per second, and division at 6000 per second. Division would not be required since averaging can be achieved by multiplication. Comparison operations are achieved at the same rate as additions. Data flow rates approaching 25,000 words a second can be achieved.

Faster data rates can be obtained by redundant use of both computers during engine operation. This may be a preferred procedure during first stage operation, and could be achieved by load sharing programs. Priority loading should still be on one computer such that this load could be transferred to the other in the event of a malfunction.

4. TELEMETRY SYSTEM CONSIDERATIONS

4.1 GENERAL REQUIREMENTS

The telemetry systems for nuclear modules or vehicles must serve the following functions:

- 1) Provide measurement data to ground test and launch systems for pre-launch checkout.
- 2) Provide continuous or demanded data as required prior to vehicle assembly in orbit, including the launch flight monitoring measurements.
- 3) Provide data to higher-level vehicle systems, including the astronauts.
- 4) Provide data communication and command links to earth tracking stations.
- 5) Provide on-board recording capability to obtain long term data trend information.
- 6) Provide select critical parameter recording, with telemetry link demand control to insure continuity of data following periods of communication blackout. (The latter would occur when earth, sun and vehicle positions prevented direct communication.)
- 7) Provide command links for changes in control programs, activating or cycling, for cycling of systems, and for remote checkout control.

4.2 TRANSMISSION SYSTEM CONSIDERATIONS

The application of telemetry transmitting equipment for deep space missions requires a trade off between power and bandwidth to achieve the desired system performance. The following criteria reflect present capability and will result in proven hardware for planetary missions in the 1970's*:

*

Private Communication, W. Ewanus, Aerospace Division of Westinghouse Electric Corporation, Baltimore, Maryland.

- 1) Greater antenna gains for a given weight dictate the utilization of upper S band (2.3G Hz), X band or possibly even K band for microwave telemetry channels.
- 2) Greater antenna gains and higher frequencies permit greater bandwidth for telemetry systems. Consideration must still be given to a trade off of bandwidth and power for optimum systems $\left[S/N \propto \left(\frac{1}{B_w} \right) \right]$. A minimum bandwidth consistent with needs must be maintained to minimize power, weight and noise in transmitting systems.
- 3) Transmitter power may be reduced with larger antennas. Multiple-channel utilization of such antennas should be designed in at the outset to help reduce system weight. IRIG carrier frequency separations which go into effect in 1970 would be a prime requirement for utilization. (This does not limit redundant antenna considerations.) An additional advantage is the reduction of antenna tracking equipment requirements.
- 4) Additional weight and power advantages may be achieved by using PCM phase modulated data transmission for both narrow and wideband data. Current systems capability, coupled with a 2 to 4 db improvement in signal-to-noise ratio (S/N), afforded by this technique strongly dictates its application in future deep space systems. (Systems are presently operational which will handle real time video to 50 mega-bits/second.)
- 5) Data compression techniques should be used to the limits of practicality to reduce the bandwidth required for telemetry and to further minimize power and weight factors.
- 6) Trade off must be made between lower power narrow band and wideband higher power transmitter systems on an overall system requirements basis. These may be determined in part by system operating and reliability requirements.

Some consideration has been given to the utilization of communication satellites in deep space repeater roles. The advantages of such systems have not been established at this time. This factor, however, may have a bearing upon final hardware designs and is included herein for information.

4.3 DATA COMPRESSION FACTORS

The need for data compression in the telemetry system has been stated primarily from the power conservation standpoint. Additional arguments have been presented (References 1 and 2) purely on the basis of receiving station capacity, storage capacity and the need for further compression on the ground for station intercommunication. Devices have made it possible to generate more data than the ultimate consumer, a human, can absorb. The need for data reduces to that which must be displayed for ground control personnel and the astronaut, data for quick access to verify what happened, and data which can provide detailed analysis of suspected problem areas when necessary. Data may be significantly compressed as long as confidence is maintained.

In considering the telemetry requirements for the proposed Mars nuclear vehicle system, the burden imposed by the payload must be considered. This burden will easily exceed the bandwidth requirements of the vehicle propulsion system. This consideration, coupled with the long term demands upon the channel allocations required for the Mars mission, further dictates the need for conservative use of telemetry allocations.

The need for on-board data compression may be summarized:

- 1) Reduced power and weight factors in interplanetary transmission systems.
- 2) Long term demands on presently overloaded telemetry channels.
- 3) The need for data compression for astronauts.
- 4) Limitations of earth tracking stations and the reduced burdens which may result if compression is employed.

The telemetry requirements after departure from earth orbit must be considered as a separate problem. The increased transmitter power and the advantages to be gained by effective antenna utilization strongly suggest a centralized telemetry system. Measurement data from the second and third stage engines must be routed via the central data processor to this telemetry system. The central data processor may weigh the measurements for the second stage Mars orbital braking operation, and later, the third stage for the return trip operation. The utilization of the central IU system can thus reduce the load on the telemetry system as well as utilize the same hardware under these two major operating conditions.

As mentioned, supplementary telemetry is recommended for handling data during first stage operation. Similar supplemental transmitters may be added to suborbital or orbital development test modules. In both cases some real time vibration channels may be desirable. These could be handled either with PCM/PM or FM/FM equipment. The real time telemetry of narrow band data from these modules can be handled with three transmitters per module, operating at 40,000 bits per second.

The compressed real time data from the IU system will require approximately 200 data points at a bit rate of 40,000 bits/second. The supplementary computed data can be handled for three channels with a bit rate of 4,000 bits per second. All measurements from the modules of stages II and III could be transmitted using two additional 10,000 bits-per-second channels. The compressed real time data could reconstruct occurrences with a 10 cycle average response while the real data could be reconstructed with a one-cycle response. Experience to date with NERVA testing indicates that this is sufficient for performance analysis purposes considering that these data include analyzed wideband measurements.

The above telemetry bit rates are based on a minimum sampling rate for a given frequency response. It would be desirable to increase these rates by as much as a factor of four. The practicality of increasing the bit rate may be decided in more detailed studies of the mission communication problem.

5. POWER SUPPLY CONSIDERATIONS

On a long term space mission, the power system will have to provide hundreds of kilowatts. The most attractive design appears to be the liquid-metal cooled fast reactor which will operate at 2000 to 3000^oF in order to allow the use of lightweight components. Combined with a potassium Rankine cycle conversion system, a power output could be expected in the 100 to 1000 kilowatt range. Also to be considered is the use of an in-core thermionic reactor with an in-core thermionic diode conversion system. Predicted power outputs for this power system lie in the 100-10,000 kilowatt range.

Regardless of the power system selected, the fact remains that to produce the power required, an advanced high-temperature fast reactor will have to be developed. Both system studies and supporting material technology work are in the initial phases at the AEC's Lawrence Radiation Laboratory.

Batteries will also play a major role in the space power systems on long term missions. Battery requirements may be divided into two areas. That is, batteries used in the Earth departure stage will not require the same storage life or charge/discharge cycling capability as the Mars braking stage and the Mars departure stage. A trade-off of storage life and high cycling capability for high energy can be made on the Earth departure stage by using lithium-copper-fluoride high-energy-density cells which can deliver energy densities of up to 200 W-hr/lb at 200-hr discharge rates with limited cycling capability and short shelf-life for activated cells. For the Mars braking and Mars departure stages, batteries with long shelf-life and capable of many charge/discharge cycles with high charging rates will be required. The nickel-cadmium cell has demonstrated superior reliability over a large number of duty cycles and an ability to accept moderately high charging rates.

Battery charge control must permit high charging rates but remain capable of reliably reducing these rates so as to insure acceptable internal gassing pressures and thermal dissipations. Coulometers, which undergo chemical changes that are proportional to the

coulombs that are passed are now used for battery charge control on the Isis satellites. Installed in series with nickel-cadmium cells, a coulometer actively signals the control wiring when a charge is returned that had previously been removed from the system. Cadmium-cadmium coulometers, used with nickel-cadmium cells have maintained cell pressures below 20 psi at temperatures above -20°C , at high charging rates.

Batteries would be used in time of peak load and when total system checkout is performed. Maximum power will be demanded during these checkout periods and during engine run times. Figure 4-1 represents a typical block diagram of the primary source and battery system. The batteries associated with each stage will be separated with each stage.

Figure 5-1 - Block Diagram of Primary Energy Source and Stage Batteries

6. PRE-LAUNCH CHECKOUT SYSTEM

6.1 CHECKOUT REQUIREMENTS

Because of the increasing complexity of flight hardware, a high degree of automation during checkout and launch will be required. The checkout system must be built around precise, reliable digital processors capable of accepting data inputs from all types of sensors, manipulating the data in real time, and providing immediate indications of the status of the unit under test. To reduce testing at the launch pad, as much subsystem testing as possible should be performed at an earlier stage. The modules under test must be designed to lend themselves readily to automatic checkout.

6.2 PRE-LAUNCH CHECKOUT SYSTEM

It will be necessary to launch five nuclear modules as separate payloads for assembly in earth-orbit. Each module must be instrumented and checked out in essentially identical fashion on the launch pad so that a complete end-to-end checkout is performed on all systems used in flight. However, one nuclear module (Stage 3 of the Mars vehicle) will contain an Instrument Unit. This Instrumentation Unit must be checked out on the launch pad. During pre-launch checkout of each of the five nuclear modules, pulse code modulation (PAM) digital data will be transmitted to the Launch Control Center via umbilical coaxial cables. Data collected from each nuclear module while on the launch pad will be made available to the Launch Control Center's computer in real time (Figure 6-1). A block diagram of the ground checkout system is shown in Figure 6-2.

There are certain prime nuclear module functions to be tested during automatic countdown on the launch pad and failure of any prime function will abort the launch. Each nuclear module will contain six reactor actuators and 24 control drums for controlling nuclear power. Each actuator may be required to individually actuate all 24 control drums at once.

Figure 6-1 - Pre-launch Checkout

FIGURE 6.2
 BLOCK DIAGRAM FOR GROUND CHECKOUT

The operation of these control drums are prime functions and during pre-launch checkout, each actuator may in turn (one actuator at a time) be commanded to rotate all 24 control drums. Proper responses to the control drum commands must be monitored; responses include the amount of drum rotation in degrees and the torque in inch-pounds. The reactor must contain poison wires during checkout to prevent the reactor from going critical; these will be removed during vehicle assembly in earth-orbit. Neutronics measurements may be made on the reactor during control drum checkout to verify reactor worth. Also, the following reactor/engine valves must be operated successfully during countdown:

- 1) Turbine Block Valve
- 2) Turbine Power Control Valve
- 3) Diluent Control Valve

During the final checkout of these valves, the Propellant Tank Block Valve must remain closed.

Other engine/reactor parameters to be monitored during countdown include:

- 1) Power Supply Voltages
- 2) Gas Storage Pressure
- 3) Propellant Boiloff Rate
- 4) Propellant Tank Level
- 5) Propellant Tank Pressure
- 6) Reactor Neutronics

At the start of pre-launch checkout, the basic functions of remote calibration and error detection provided by the data acquisition and malfunction analysis systems would be utilized. Check problems would be fed into the guidance and control computer in the Instrument Unit and the data acquisition system would provide countdown data to the Launch Control Center.

Step by step automatic sequencing must verify that all systems are functioning properly and are in a ready-to-launch condition. Malfunctions must be isolated at subsystem levels.

6.3 LAUNCH AND ORBITAL MONITOR SYSTEM

During launch of the nuclear modules, it will be necessary to continuously monitor data from each module until it reaches earth-orbit. Likewise, after the nuclear modules have been placed in earth-orbit for vehicle assembly, it will be necessary to periodically monitor data from each module to verify whether or not all modules are functioning properly and are in a ready-to-assemble condition. Assembly time of the Mars vehicle is estimated to be 120 days. To accomplish the monitoring of data from the nuclear modules during launch and prior to vehicle assembly, the launch nose cone on each module will contain batteries and receiver/transmitter telemetry equipment which will transmit PCM/PM digital data to automatic data handling equipment on the ground (Figure 6-3). Upon assembly of the nuclear modules into the Mars vehicle configuration, the launch nose cones will be discarded and the vehicle Instrument Unit will provide the data acquisition link with the ground stations.

FIGURE 6.3
INSTRUMENTATION BLOCK DIAGRAM FOR EARTH ORBIT

* LAUNCH Nose Cone Elements discarded in earth orbit at vehicle assembly.

7. CONCLUSIONS AND RECOMMENDATIONS

The requirements for the nuclear subsystem instrumentation have been directed toward the end vehicle application. Certain needs of subsystems in the overall application have been established in this approach to the problem. Flexibility demands equipment to accommodate changing mission requirements as has been shown. This factor is important in equipment weight reduction and reliability, and has been stressed throughout this study.

The need for further study of mission applications to increase detailed equipment design requirements is also apparent. It is particularly evident that the nuclear environment in equipment areas must be more precisely determined for worst-case mission conditions. From this information, the most attractive tradeoff between shielding and circuit hardening may be determined.

The needs of the astronaut for data and data system control have been developed. The communication problems inherent in interplanetary missions demand increased local control by the vehicle crew. Maintenance and alarm data must be obtained for planning corrective action on a local basis. Higher mission reliability may thus be obtained.

The following recommendations are suggested for continuation:

- 1) Further study of mission requirements, including environment factors, is required to increase definition of equipment requirements.
- 2) Breadboard systems, based upon the final requirements, should be incorporated into ground test programs at an early date to validate designs.
- 3) A study of available system components should be made to determine development requirements to flight hardware.
- 4) Prototype systems should be applied to ground testing of engine systems far in advance of flight application requirements.

- 5) Consideration of module testing requirements should be given in the E/STS 2-3 and all test facilities at the time they are designed.

The requirements outlined in this study, particularly the need for system checkout in orbit, suggest an urgent need for full testing and reliance on flight equipment during ground tests well ahead of flight missions.

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