NUCLEAR DIVISION

Proposal No. ND-681118

STUDIES OF FFTF SURVEILLANCE - INSTRUMENTATION REQUIREMENTS

In Response to RFPRM5

From

Battelle - Northwest

Battelle Memorial Institute/Pacific Northwest Laboratory

Richland, Washington

30 April 1968

MASTER

FILE COPY

AGC-ND

Technical Document Center

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

TECHNICAL DOCUMENT CENTER
Nuclear Rocket Operations

DOC. NO. AI-1501

AGCS 0120-48

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

AEROJET

GENERAL

Proposal No. ND 681118

**STUDIES OF
FFTF SURVEILLANCE - INSTRUMENTATION REQUIREMENTS**

In Response to RFPRM5

From

Battelle - Northwest

Memorial Institute/Pacific Northwest Laboratory

Richland, Washington

30 April 1968

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

AEROJET - GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

S

Aerojet-General Corporation's SWAT (Stress-Wave-Analysis Technique)
System, Model MM, for On-Line Detection of Growing Flaws in Pressure Vessels.

Figure 1

This portable SWAT system accepts stress-wave data from sensors on a high-strength metal pressure vessel and monitors these signals for indications of crack growth during the manufacturing pressure qualification test. Upon receipt of stress-wave information, the signal is converted from an analog to a digital signal, recorded, and displayed. This SWAT system can be programmed to interrupt or continue the test as desired. The system evolved from years of experience in NDT monitoring of Aerojet build pressure vessels and component parts.

CONTENTS

	<u>Page</u>
I. Introduction	I-1
A. Format and Criteria	I-2
B. Analytical and Applications Discussion	I-4
1. Analytical Studies	I-4
2. Instrumentation Application	I-6
II. Summary	II-1
III. Experience	III-1
A. Surveillance Requirements and Systems	III-1
1. The SWAT (Stress-Wave Analysis Technique) Monitoring System	III-1
2. NERVA Engine Exhaust System Monitor (FD&S)	III-5
3. System Data System	III-7
4. The Vibration Instrumentation System	III-13
5. High-Frequency Data Monitor and Control Unit (CSM)	III-17
B. Analysis Techniques	III-22
1. Nuclear Analysis	III-22
2. Thermodynamic Analysis	III-31
3. Material Evaluation	III-34
4. Radiation Effects	III-40
5. Stress, Strain, and Vibration	III-45
6. Reliability and Quality Control	III-50
7. Safety Analysis	III-55
8. Costs	III-59
C. Program of Investigation	III-60
1. Application Philosophy	III-60
2. Instrumentation and Inspection Examples	III-63
D. Related Contracts	III-75
1. Pacific Northwest Laboratory-Battelle	III-75
2. United States Atomic Energy Commission	III-78
3. The National Aeronautics and Space Administration (NASA)	III-79

CONTENTS (cont.)

	<u>Page</u>
4. The Space Nuclear Propulsion Office (SNPO); Joint Agency of the AEC and the NASA	III-84
5. United States Navy	III-89
6. United States Air Force	III-91
7. United States Army	III-94
8. United States Department of Defense (DOD)	III-94
9. Lawrence Radiation Laboratory	III-94
10. Argonne National Laboratory	III-95
11. Commercial	III-95
E. Background Experience	III-97
1. SNAP 8 Power-Conversion System	III-97
2. Nuclear Engine Rocket Vehicle Application (NERVA)	III-108
3. Nuclear Rocket Engine Test Stand No. 1	III-115
4. Alkali Metal Evaluation Program	III-118
5. Army Gas-Cooled Reactor System Program (AGCRSP)	III-122
6. Aerojet-General Nuclear Industrial Reactor (AGNIR)	III-126
7. AGN 201 and 211 Commercial Training Reactors	III-129
IV. Management	IV-1
A. Study Organization	IV-1
1. Responsibilities and Authority	IV-2
2. Project and Back-Up Personnel	IV-8
3. Project Plan	IV-102
B. Plan, Schedule, and Control	IV-110
1. General Concept	IV-110
2. Management Information System Components	IV-112
C. Estimates Costs and Other Factors	IV-117
1. Estimated Costs	IV-117
2. Project Location	IV-119
3. Present Workload	IV-119
4. Design and Engineering Facilities	IV-121
5. Outside Assistance	IV-130

TABLE LIST

<u>Table No.</u>		<u>Page</u>
1	Nuclear Analysis Programs Available in Aerojet (Exclusive of Peripheral Programs)	III-30
2	Summary of Combined Nuclear Testing Performed During the Past Year	III-43
3	Listing of Some of the Tested Materials	III-44
4	Methods of Inspection	III-60

FIGURE LIST

<u>Figure</u>		<u>Page</u>
1	Aerojet-General Corporation's SWAT (Stress-Wave-Analysis Technique) System Model MM, for On-Line Detection of Growing Flaws in Pressure Vessels	ii
2	Advanced SWAT System Incorporating Digital Computer Capability for Flaw Detection and Location, and Other Diagnostic Capabilities	III-4
3	Facility, Duct, and Shield Monitor-Control Point	III-6
4	Simplified Version of the Data System	III-9
5	Equipment Block Diagram for Processing Wide Band Data	III-11
6	Hybrid Spectral-Analyzer System Schematic	III-12
7	Vibration Instrumentation System	III-14
8	PCS-4 Vibration System Basic Block Diagram	III-15
9	System Block Diagram at Combustion Stability Monitor	III-19
10	A Functional-Interface Flow Diagram	III-23
11	Neutron Spectra at Three Axial Locations	III-25
12	Axial Distribution of Gamma Ray Dose Rates - Unshielded	III-26
13	75,000-lb-Thrust NERVA Flight Engine	III-109
14	Engine Test Stand No. 1; Nuclear Rocket Development Station, Nevada	III-115a
15	Gas-Cooled Reactor Experiment Showing Reactor Located in a 30-ft-Deep Pool of Water at NRTS, Idaho	III-124
16	SNAP-8 (PCS-1)	IV-ii
17	Project Management, Both Phases	IV-3
18	Project Engineering, Phase I	IV-5
19	Project Engineering, Phase II	IV-7
20	Project Plan	IV-103
21	Map of Aerojet-General Sacramento Facility	IV-120

I. INTRODUCTION

Aerojet-General Corporation believes that it is to the advantage of the FFTF Project, and subsequently to the Government, that Aerojet be considered a prime candidate to perform the work scope described in RFP RM-5, titled Surveillance Instrumentation Requirement Studies. In the broader sense, criteria for evaluation of this proposal should include the capability of complex analysis developed by Aerojet in nuclear power plant design and construction, and Aerojet's leadership for more than a quarter century in building rocket engine systems, test sites, and production facilities in the aerospace field.

Aerojet-General Corporation has experience in surveillance instrumentation monitoring requirements and is a leader in designing, analyzing, and constructing surveillance systems.

Aerojet's Nuclear Division is pleased to present this proposal. A successful program is ensured by the availability of a well-qualified staff that is extremely interested in this project, and by the specialized equipment available for use on this program. The total background of Aerojet's efforts in aerospace surveillance and nuclear engineering has been combined through the Nuclear Division's coordinated efforts in this proposed program.

The operation of the Nuclear Division coordinates the Corporation's resources and capabilities relative to current and expected efforts in the nuclear-engineering community. The Nuclear Division currently consists of 1200 employees (excluding 2000 employees of the Idaho Nuclear Corporation - also under Division cognizance), of which 35% are professional personnel. Major programs now being conducted by the Nuclear Division include NERVA, SNAP-8, liquid-metal research, power-systems development, nuclear-materials evaluations, LMFBR fuel-element fabrication (EBR II driver fuel pins), and the study of FFTF remote-handling systems.

A major Nuclear Division long-range goal is to become an active participant in the research, development, and construction of LMFBR's. Aerojet-General's Nuclear Division believes that, through participation in such activities as presented in this proposal, the facilities, technologies, and capabilities of its personnel will prove to be complementary to the requirements of the Atomic Energy Commission and its contractors.

A. FORMAT AND CRITERIA

The format of this proposal complies with all the needs of the study and those of the evaluators. The criteria formulated by PNL in RFP RM-5 are restated with some suggested modifications and discussions of those modifications.

For simplicity, this proposal has Introduction, Summary, Experience, and Management Sections. The Introduction and Experience sections are arranged in order of criteria for evaluation stated in RFP RM-5: (1) experience in determining surveillance.....requirements.....; (2) capability for performing analytical studies.....; and (3) capability for applying instrumentation..... Where appropriate, paragraphs in the Experience Section will include: (a) genesis of problem under discussion; and (b) approach to solving the problem and experience in solving similar problems. In the left margin of both the Experience and Management Sections are numbers corresponding to the RFP RM-5 numbers of the Questionnaire-Instruction List. An "e" alongside the marginal number indicates that further discussion of that portion of the Questionnaire may be found "elsewhere" in that section. For example, (10) e indicates that the paragraph is in response to Questionnaire question 10 and that other portions in answer to that question may be found in preceding or subsequent portions of the section. Answers to questions 1 and 10 may be found in the Experience Section, all other answers may be found in the Management Section. For simplicity, the Management Section IV also has a detailed Table of Contents with the Questionnaire-answer locations indicated.

The criteria for evaluating the proposals as set forth in RFP RM-5, as modified, where underlined, follow:

- a. Experience in determining surveillance instrumentation monitoring requirements for operating plant primary components (reactor vessel piping-replaced by underlined).
- b. Capability for performing analytical studies in hydraulically or mechanically induced vibration, thermal expansion, crack formation, and neutron damage.
- c. Capability for applying instrumentation and instrumentation systems to measuring the following types of parameters on plant primary components: (reactor vessels and piping-replaced by underlined)
 - (1) Ultrasonic inspection
 - (2) Visual inspection
 - (3) Vibration measurements
 - (4) Displacement measurements
 - (5) Acoustic emission
 - (6) Noise analysis
 - (7) Other

Relative to criteria (a) and (c), although the problems expected to be found in the plant are pertinent to reactor operation, the broader sense of primary plant components is recommended here for two reasons:

(1) there is more to the primary system than vessel and piping, this system among other things, includes pumps, sodium heat exchangers, and valves, and
(2) although it is recognized that in making a primary component analysis and establishing a surveillance criteria, knowledge of reactor plant operation is important, much of the primary system is in a low-radiation environment and consists of pipes, valves, and heat exchangers. Since, as mentioned earlier, Aerojet has done both advanced analysis and implementation of surveillance instrumentation monitoring systems in the aerospace and nuclear fields, it should be well qualified for the difficult task at hand.

Criteria (c) has been expanded to include instrumentation systems and other parameters. Experience in applying instrumentation is only a

portion of the qualification needed for final creation of a surveillance instrumentation monitoring system. Proposals should be evaluated relative to experience in converting instrument signals into meaningful diagnostic information and possibly a control system for safe, continuous operation of the plant.

Aerojet has also evaluated instruments that may be able to detect other parameters than those listed, possibly indicating that on a developmental basis, these tools may be useful in isolating problems that cannot be detected conventionally.

The criteria as modified, are believed to provide PNL with a broader guide for evaluating the submitted proposals. It can be expected that the proposal that best meets these modified criteria will perform to the best advantage of the FFTF Project and the Government.

B. ANALYTICAL AND APPLICATIONS DISCUSSION

As the field of reactor technology has advanced to include higher power and power density and more complex and increasingly expensive test systems, considerations of both economics and safety have led to increasing demands for surveillance and in-service inspection techniques to help prevent unnecessary failures of equipment or design inadequacies. This development parallels or follows that in other industries. Failure of inexpensive components or parts can jeopardize the capital investment in a multimillion dollar space engine.

1. Analytical Studies

Solutions to problems created by the more stringent operating environment of the liquid-metal system and the use of on-line and post-operation surveillance systems are needed. The problems can be categorized relative to materials, performance characteristics, (dimensional stability

monitoring systems can be developed once the problems are recognized), and safety. Relative to the study solicited in RFP RM-5, basic data for these problem areas should be provided for the materials, particularly for the effect of sodium and radiation on the physical properties of austenitic stainless steel.

Data on physical properties, as a function of time and environment (sodium, radiation, and temperature)--such as tensile and yield strength, creep rate, stress-to-rupture, fatigue life (in particular, low-cycle), strain-hardening coefficients, ductility, etc., as well as corrosion effects should be determined. These data now are not fully available for the major materials and designs of interest. Similarly, the effects of fabrication processes on materials properties, in particular weld materials and heat-affected zones of weldments need be considered.

The relatively high thermal conductivity of sodium leads to more severe thermal transients and flow and temperature maldistribution than normally encountered in water systems--thereby creating greater thermal-stress conditions. Also, the significance of thermal transients is further increased by the greater thermal expansion and lower thermal conductivity of the austenitic steels, compared with the ferritic steels. Therefore, analysis for both vessel and piping must be evaluated for potential problem areas.

The primary system design must provide for safety during a Design Basis Accident. The analysis must evaluate the accommodation of the kinetic energy acquired by various parts involved in nuclear-power excursions.

All analysis and testing should be performed within the framework of a quality-assurance and reliability program to ensure industrial capability to reproduce the desired effect. Methods of failure and reliability analyses should be prepared or developed for use in these analyses.

2. Instrumentation Application

The long term environmental effects of sodium and radiation on material properties are not well understood and are not supported by statistical performance data. Therefore, in-situ surveillance of the vessel and related structural components is required. A system for continuous monitoring using instrumentation for detecting leaks or indicating incipient failure must be developed. However, until such systems are perfected, or in conjunction with them, techniques for periodic inspection--concurrent with reactor refueling to minimize plant downtime--should be required. Even after development of suitable instrumentation, such inspection may still be needed, although at a reduced frequency.

The development of a conceptual design of a monitoring system will be predicated on the analysis discussed in the preceding section and on the availability and development of instrumentation.

Traditionally primary components have been subjected to various tests and inspections throughout the course of their operating history to demonstrate that continued operation will not result in catastrophic failure. Most of the techniques currently employed for similar inspections and tests for nuclear components are patterned after those employed in general component use. The comparatively more critical function of nuclear components and the greater attendant difficulty of inspection due to radioactivity following operation places even greater emphasis on the meaningfulness of these inspections and tests.

Hydrostatic testing has had a long history of Code usage as a technique for inspecting closed vessels or pipes. It usually is recognized as a useful leak and strength verification test and it may often serve to detect improper design, gross flaws, faulty materials, and to evaluate brittle fracture susceptibility. This test method is believed to be beneficial in

preventing brittle fracture by the mechanisms described as plastic reshaping, mechanical stress relief, stress redistribution, notch nullification or crack blunting, and localized strain hardening. Conversely, it may have an adverse effect because of excessive deformations and metallurgical damage from overstressing, for example, embrittlement.

It is common practice to subject components to nondestructive examination at periodic intervals. The usual techniques employed are unaided or optically augmented visual and liquid-penetrant examinations. These same techniques are probably applicable to nuclear components. Currently, visual examination is the most common technique.

Periodic examination of nuclear components is impeded by (a) the requirement that inspection must coincide with scheduled reactor shutdown; (b) the design of internal and external reactor core and/or vessel components impedes or prevents access for inspection, and (c) the intense background radiation limits human access and restricts the application of visual techniques. These restrictions and recognition of the inherent limitations of unaided visual examination have spurred Aerojet's interest in developing techniques for performing more meaningful periodic examinations and/or continuous in-service examinations.

The most promising examination methods appear to involve some form of acoustic phenomena (either sonic or ultrasonic), although radiography and other methods have been considered. Conceptually, either fixed-probe or mechanical-scanning-probe acoustic systems appear feasible.

A fixed-probe acoustic device can be developed as an active system in which the probe generates and receives energy or as a passive system in which the probe only receives the energy generated by other conditions. For either of these fixed-probe systems, further development would be required before an operational system could be used as a standard test.

Intensive effort is also being expended on passive systems based on the phenomenon of acoustic emission. Detectors would be placed at strategic locations to monitor acoustic stress waves released as a consequence of metal deformation or crack propagation. As with previously discussed systems, further development effort would be required before an acoustic emission system could be considered as standard for operational examination.

Even with the most careful attention to materials specifications, design details, fabrication procedures, and inspection procedures, it is currently not possible to maintain the initial materials properties or to predict unfailingly any change or deterioration of materials properties with time. The overlapping and possibly opposing influences of environmental parameters, such as radiation, temperature, stress state, possible corrosive action, etc., preclude a thorough and precise knowledge of the effect of a single environmental parameter.

The designers currently fulfill a portion of this obligation by conducting a materials radiation surveillance program generally in accordance with ASTM, "Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors." These programs are implemented by subjecting tensile and impact material specimens, taken from beltline courses of the shell, to temperature and radiation conditions representative of that seen by the vessel. The continuous monitoring of the radiation-induced changes thereby permits evaluation of the safety and reliability of continued operation of the vessel for the prescribed approved operating conditions.

II. SUMMARY

Aerojet-General Corporation has broad experience in determining surveillance instrumentation monitoring requirements through its development efforts over a period of 26 years. Through its long history in aerospace activities Aerojet is able to apply aerospace techniques of system analysis, problem definition and solution; technical documentation, and widespread controlled distribution of technical information for this proposed study.

Aerojet-General Corporation in the Aerospace and Nuclear fields has determined surveillance instrumentation monitoring requirements, and is a leader in designing, analyzing, and constructing surveillance systems. Examples of these systems are:

- a. SWAT Monitoring System
- b. NERVA Engine Exhaust System Monitor
- c. System Data System
- d. Vibration Instrumentation System
- e. High-Frequency Data Monitor and Control Unit

Analysis experience and techniques are needed in a multitude of disciplines in order to perform the study proposed. These disciplines appear to be in the areas of Nuclear Analysis; Thermodynamic Analysis; Material Evaluation; Radiation Effects; Stress, Strain, and Vibration; Reliability and Quality Control; and Safety Analysis. Aerojet-General has experience in these areas through work with government and private agencies on projects such as: NERVA, SNAP-8, ML1, AGN 201, AGN 211; and, in addition is familiar with the FFTF design through the following contractual activities:

FFTF Phase II Alternate Reactor Arrangement
FFTF Fuel Handling System Conceptual Design Study
Study of Alternate Split Conical Core

Integration Study of Fuel Handling and Radioactive Maintenance
System

Consultant Services for Program Evaluation System

The project organization that can be made available immediately for this work is well versed in all technologies pertinent to a Surveillance Monitoring System for Liquid Metal Fast Breeder Reactor Plants. The management for this study effort will establish plans, schedules, and controls in keeping with Battelle's own system of evaluation and control. The Nuclear Division's management is interested in this study, and considers it vital that they review progress and monitor program direction as the need arises so that the results of the effort are in the best interests of Aerojet's performance and endeavors in the FFTF program. Aerojet-General feels that it can perform the study completely as requested and in the time allotted by the contractor.

An estimated cost for Phase I of the study effort has been evaluated to be \$41,000. Phase II costs have been split into two parts: Part A is for the literature search while Part B is for system conceptual design. These estimated costs are: A \$58,000 and B \$206,000 respectively.

It is further herein recommended that the proposal evaluation criteria include experience in designing and building surveillance monitoring and data acquisition systems, and that Part B of Phase II, Conceptual Design of a Surveillance Monitoring System, start at an early stage during the Phase II literature search activity. The estimated costs were arrived at by evaluating the required results of this study and the techniques necessary for providing them. Data that Aerojet is unaware of may be made available during the study by PNL thus materially reducing the estimated costs. In addition, it is altogether possible that PNL may require lesser or deeper analysis in a particular area or areas than now seem necessary. Such additions or deletions, of course, will affect the estimated costs of this study.

III. EXPERIENCE

Aerojet's experience is discussed in proposal criteria order:

a) experience in surveillance requirements and systems; b) analysis techniques; and c) parameter investigations. In addition, related and background experience in nuclear power plant and liquid metal technology is also discussed.

A. SURVEILLANCE REQUIREMENTS AND SYSTEMS

Aerojet has evaluated the need for monitoring instrumentation and has actively applied the criteria set and the instrumentation and system experience gained over the years to real time hardware diagnostic surveillance and monitoring systems. In this section Aerojet's experience is illustrated in requirements and system application by presenting a description of five systems developed, designed, and operated by Aerojet in other Aerojet plants or in other Aerojet studies. These systems are the SWAT Monitoring System, the NERVA Engine Exhaust System Monitor System, the System Data System, the Vibration Instrumentation System, and the High Frequency Data Monitor and Control Unit.

[(1)(10)e*] 1. The SWAT (Stress-Wave Analysis Technique) Monitoring System

Aerojet-General's experience indicates that the major cause of failure of pressure vessels and piping that successfully completed hydrostatic tests is slow crack growth. The advent of fracture toughness testing and the use of fracture mechanics during the design stages testifies to the significance of crack-growth relationship to structural reliability. Crack formation, whether due to gross plastic deformation or to included flaws that propagate incrementally create acoustic/stress-wave emissions. This phenomenon has increased interest in the development of techniques that can be applied

*Indicates this discussion and discussions "Elsewhere" in this major Section answer in part questions (1) and (10) from RFP RM-5 Questionnaire - Instruction List.

during periodic inspections as well as in continuous in-service examination. In addition, less reliance on visual examination of the vessel or on the inspection data would establish a more efficient inspection process.

Usually nuclear plant environmental parameters tend to increase the yield strength and decrease the ductility of the material used. This time- and exposure-dependent embrittlement process explains why a material fails because of brittle fracture at normal operating temperatures. The sudden failure of reactor components due to brittle fracture could cause catastrophic rupture of major structural components. Therefore, even more than flaw growth attributable to ductile mechanisms, the possibility of brittle fracture is significant in the long-term reliability and operational safety of nuclear power stations.

The application of techniques that provide in-service inspection surveillance has been an important consideration to Aerojet-General Corporation during the design and development of the Stress-Wave Analysis Technique (SWAT). These considerations have ranged from developing criteria for incipient failure and nondestructive testing of the reactor pressure vessel and other major components, to continuous surveillance for anomalous performance due to pump cavitation and wear, fluid leakage, and nucleate boiling.

Nondestructive examination methods currently in use are radiography, ultrasonic examination of welded joints, magnetic-particle examination, and liquid-penetrant examination. These techniques are usually applied during and after manufacturing, prior to hydrostatic tests, and periodically during plant shutdowns, material surveillance and hydrostatic retests. Most of the suggested supplementary methods for continuous in-service surveillance involve some form of acoustic phenomena, either sonic or ultrasonic, although radiography and other methods have been considered. The use of acoustic inspection systems requires an understanding

of wave propagation characteristics such as attenuation, mode conversion, and dispersion. These studies have been made and are continuing under Aerojet programs.

The potential application of acoustic/stress-wave emission detection techniques to the surveillance of nuclear reactor pressure vessels and piping is being investigated by the Atomic Energy Commission. Some of the initial problems have been resolved and others are being intensively studied. Operational noises of nuclear reactor plants, long considered to be a major problem, have been considerably and almost completely eliminated through narrow band or high pass filtering. With this technique the vibrational and mechanical background noise level can be virtually eliminated by blocking the frequencies below 10-20 kHz.

Aerojet's experience indicates that proper instrumentation engineering relative to sensors, spacing, attachment, amplification, frequency band width, and logic circuitry design virtually eliminates mechanical noises due to operational systems.

SWAT system use as a major component failure-warning system, particularly to detect metal overstressing and slow-crack growth, has been augmented by its ability to function as an on-line monitor of the in-service degradation of operational systems (Figure 1). This on-line monitoring includes detecting leaks from valves or lines and sensing the instabilities associated with pump cavitation and nucleate boiling (Figure 2 of SWAT Second Generation System). In addition, changes in the received acoustic emission spectra due to wear or other malfunctioning processes has been evaluated with regard to maintaining long-term operation at minimal expense.

Operational system noises can be analyzed as indications of poor performance and malfunctioning. Pump cavitation, for instance, has been known to produce complete structural failure of pumps; however, even

A second-generator SWAT capability available for application to the proposed program is the advanced 16-channel test system shown here. This universal test system has been developed at Aerojet and includes the use of a digital computer to process, analyze, and display the stress-wave emission data. The digital information can be handled in two modes. The first is a data-logging method that presents all the information processed through the digital logic networks to a visual display and simultaneously records these data and the time at which they occurred, both on punched paper tape and as a typewritten record. The primary use of this data-logging method is for long-term surveillance of noncritical structural components, time-dependent material-properties tests, and other applications where the using agency does not require an immediate response action.

The second mode in which the stress-wave data may be handled is more universal in nature. In this mode, all the digital stress-wave data and any other pertinent information, such as temperature, pressure, load, and strain, are furnished internally to a general-purpose digital computer. This general-purpose computer can be programmed to operate on the data in any manner desired by the user. Triangulation programs for test specimens of arbitrary configuration have been developed so that flaw location can be automatically furnished as data output. Through this system, all possible data-handling techniques can be automatically accomplished and displayed, in real test time, so that decisions or actions may be taken. The computer can also be scheduled to make decisions and react, responsively, to any pre-established situation in applications where long-term surveillance of critical components is of primary importance.

Figure 2

before failure occurs, this phenomenon can seriously reduce system performance. Erosion, the primary source of the structural failures, is only one of the many effects that can occur due to cavitation. Tests have shown that spectrally analyzed accelerometer data can be used to detect the cavitation phenomena. Similarly, leak detection and nucleate boiling are detectable through the use of on-line continuously monitoring instrumentation techniques.

Aerojet has made studies, conceptual designs, and applied the use of stress-wave-emission techniques to pressure vessels and piping in the following areas: reactor pressure vessels and piping; submarine hull pressure vessels; petroleum industry pressure vessels and piping; gas and oil pipelines, aerospace propellant tankage; pressurized gas storage bottles; and other varieties of pressure vessels.

[(1)(10)e] 2. NERVA Engine Exhaust System Monitor (FD&S)

The nuclear engine exhaust system for the NERVA engine test stand, including the exhaust duct and engine compartment shields designed by Aerojet, is considered an important system for the safe operation of the engine/reactor system (a portion of the system is illustrated in Figure 3). The complexity of this system necessitated full instrumentation to ensure that it is properly monitored during an engine test. An analysis was performed by Aerojet to define the parameters essential to monitoring the safe operation of this system. These parameters established by systems analysis were then used by Aerojet to establish requirements and design criteria for a system to monitor the numerous critical parameters involved. These parameters encompassed physical measurements that included pressure, temperature, flow, strain, vibration, vacuum, leak rate, gas analysis, and displacement. The criteria and requirements resulted in a Duct and Shield Monitor System designed by a subcontractor under the technical direction of Aerojet. Aerojet directed the system installation, activation, and operation.

Figure 3 - Facility, Duct, and Shield Monitor-Control Point

Since the transducers and sensing systems used on the duct and shield system were located in a severe radiation environment, Aerojet designed and installed the transducer and sensing systems that provided the necessary inputs to the Duct and Shield Monitor System.

The system as designed is essentially a hybrid computer that has 70 input channels of the type indicated, through suitable signal conditioning into a time division multiplexer, and then to a A to D converter for remote transmission. The data is processed through preselected proportionality or programmed linear approximation into engineering units. Some channels are displayed, constantly, depending on frequency-response conditions, or are displayed on a selective basis using a go-caution-alarm (GCA) status display. The GCA provides comparison of the input channels with presettable caution and alarm levels. In addition, the system provides for full-scale and zero-reference levels check out system operation.

The system, in essence, supports the test operator by providing the capability to constantly monitor a large number of critical parameters and to give caution or alarm indications to the operator if system anomalies or disturbances occur in or on-line operation conditions.

[(1)(10)e] 3. System Data System

The objectives and goals of the data analysis are to evaluate performance and to insure that the design has not degraded and that the performance as defined by prediction is optimum. In this manner, the use of the data acquisition system analysis, the corrective action taken, and the follow-up become an integrated part of the qualification and test program. To support the Aerojet systems analysis in the liquid and solid rocket and in the nuclear programs, the objectives and goals are functionally described in terms of design commitments, maintenance requirements, and performance requirements and specifications. That is,

measurements and analysis must be tailored to specific objectives to be meaningful. These objectives must be specified in numerical terms, together with specified requirements and capabilities for enabling acceptance-rejection criteria, required action, and necessary feedback for each particular objective.

To demonstrate the method of carrying out what Aerojet terms the "system data system" approach, two goals will be described for an analysis program.

a. Design Adequacy

The system is defined by mathematical relations. For dynamic analysis these mathematical relations are converted into complex or frequency domain relationships. Significant to the programs developed at Aerojet are traditional technical programs to compute transfer functions and options designed to enable instantaneous corrective action. For example, coherence functions are plotted to indicate the reliability of the data, and several options are developed to provide sampling, weighting, selecting, and evaluating data applicable only to the specific conditions of the data. Graphical as well as analytical controls (flags) are designed into the analytical system. Since the design model includes mathematical equations, a pole-zero routine describes a similar mathematical model so that each parameter to be evaluated can be assessed. These test data results are then compared with predicted results and an immediate evaluation can be made because previous test data have also been included in the analysis model. A simplified version of the data system is shown in Figure 4.

b. Detection of Crack Forming

To achieve the objective it is essential to use specimens without cracks and specimens with progressively larger cracks. Using these as standards, an analytical set of requirements will have been established. This can be done through the use of data already compiled by Aerojet

Figure 4 - Simplified Version of the Data System

from materials research using the SWAT monitor. To illustrate, a crack may appear as increase in amplitude, change of frequency, or a shift in time. Significantly, the data system must be set up for each potential mode of failure. Therefore, a unit of measure must be established for each mode of failure. Typical units of measure that are expected to be evaluated and used are amplitude vs trace frequency; phase shift and damping factor to detect dynamic changes; autocorrelation to detect time lags or shifts; and power spectral density to detect energy shifts.

The data acquisition and programs to support the "systems data system" already exist at Aerojet. Aerojet data acquisition and analysis capabilities have already been developed to support liquid and solid rocket and nuclear rocket test programs, ML-1 reactor, SNAP-8, and other related projects. This experience can be applied to the instrumentation and monitoring system program for the evaluation of vibration, displacement and acoustical measurements, and for noise analysis.

Figure 5 shows a flow diagram that indicates the Aerojet data-processing procedure for wide band (above 5 cycles/sec). Unique features of this system include a high-speed data digitizer (10,000 samples/second) and a hybrid spectral analyzer. For FFTF wide-band requirements the system can be used in a manner similar to that of the NERVA program.

The hybrid spectral analyzer (Figure 6) with a time-compression, digital-delay, line-storage technique can perform on-line spectral analyses that would be useful for dynamic test and vibration data analysis.

In support of the data acquisition effort, various digital programs have been developed and used by Aerojet for data analysis. These programs, which can be readily adapted to a FFTF surveillance and monitoring system, include: (1) general analysis program (Program 40/174);

Figure 5 - Equipment Block Diagram for Processing Wide Band Data

Figure 6 - Hybrid Spectral-Analyzer System Schematic

(2) mechanical impedance function program (Program 2905); (3) power spectral density program; (4) random transfer function program (Job 2907); (5) deterministic transfer function program (Job 2909); and (6) finite pole-zero program (Job 2906).

[(1)(10)e] 4. The Vibration Instrumentation System

A vibration instrumentation system shown in Figure 7 was designed and installed during the SNAP-8 Program to monitor the vibration/acceleration of various components in the liquid metal test cells.

The vibration instrumentation system is designed to have the following functions:

- a. Indicate continuously acceleration on individual voltmeters.
- b. Record for short periods of time vibration signals on a high-speed FM tape recorder.
- c. Record continuously two vibration channels on a continuous recorder.
- d. Analyze vibration signals on a sonic analyzer.
- e. Provide audible reproduction on a continuous basis of any given vibration signal.

Figure 8 illustrates the over-all vibration instrumentation system in form of a block diagram. The following description describes this drawing. The system is described in the same direction as the vibration signal is routed.

VIBRATION SYSTEM RECORDING-INDICATING EQUIPMENT

14-channel high-speed tape recorder - center rack.

Continuous tape recorders - right rack.

Audio controls, switching system, and sonic analyzer - scope-like device - left rack.

Figure 7

VIBRATION BLOCK DIAGRAM

Basically a 12-channel system with the following indicators-recorders:

14-channel high-speed tape recorder utilized for data points.

4 channels of continuous recording with 1-hr capacity - provides record of any malfunction or failure. Critical measurements only on these recorders.

A sonic analyzer (graphical display of frequency vs g level).

An audio system to provide on-line "feel" to operators.

Selector-switch system provided so that any accelerometer can be displayed on analyzer or listened to on the audio system.

Playback of recorded information through analyzer and audio system possible through switching system.

The use of audio vibration output on-line is highly recommended. It provides the operators and design engineers with a real practical feel that has proved to be more sensitive than using most other systems.

Figure 8

a. Standard System (12 Channels)

(1) A quantity of 1 to 12 accelerometers located in the liquid metal cells send their signals to 12 charge amplifiers in the signal conditioning room.

(2) All of these 12 channels can be simultaneously recorded on the tape recorder.

(3) Two specific channels of these 12 can also be simultaneously recorded on the Concertone Continuous Recorder.

(4) Any one of these 12 channels can be visually observed in real time on the sonic analyzer by use of the Analyzer Selector Switch, which must be manually connected to the analyzer.

(5) Any one of these 12 channels can be audibly monitored in real time by use of the 13-position Audio Selector Switch and by having the direct-reproduce selector switch in the "direct" position.

(6) Any one of these 12 channels can also be reproduced from the tape recorder on the sonic analyzer by: (a) selecting the desired channel on the "Reproduce Head Selector" switch; (b) turning the Direct-Reproduce Selector Switch to the "Reproduce" position; and manually connecting it to the analyzer.

(7) While the channel is reproduced on the sonic analyzer as described in Paragraph (6), it is also automatically audibly monitored through the speaker located in the control room ceiling.

b. Back-up Accelerometers

Two back-up accelerometers (a-2 and a-4) are mounted. Cabling from both transducers extends into the test cell. However, only one of these accelerometers is physically connected to Channel I of the Dyna-Monitor located in the cell. This channel is directly connected to the No. 13 position of the Analyzer Selector Switch and can be visually monitored on the sonic analyzer. This channel cannot be audibly monitored.

c. Microphone

One microphone is installed to monitor test cell background noise and direct sound measurement. This microphone is connected to Channel II of the Dyna-Monitor in the cell. This channel is directly connected to the No. 13 position of the Audio-Selector Switch. When the Direct-Reproduce Selector Switch is in the "direct" position, this channel is heard through the speaker. This channel cannot be connected to the sonic analyzer.

d. Audible Reproduction

Data from the Concertone and Ampex tape recorders can be heard through the speaker by manually connecting to the audio-amplifier. The Ampex Tape Recorder is not part of the vibration measuring system but is used for voice recording of control room personnel.

[(1)(10)e] 5. High-Frequency Data Monitor and Control Unit (CSM)

Unstable processes, resulting in periodic signals from accelerometers and pressure-sensing devices in the range of 0.6 to 10.0 kHz, can be monitored through the use of an Aerojet-designed combustion stability monitor. This all-solid-state module, capable of handling up to four input circuits simultaneously, can be adjusted for threshold (input level), band

pass, and time delay, providing a relay contact closure when all of the desired combinations of input conditions are met. Thus, signals below a certain amplitude can be excluded. Signals outside of a predetermined pass band can be excluded through the use of active filters. Finally, to avoid false signalling on brief noise spikes or chatter, relay trip-delay times can be inserted.

This device has been used successfully by Aerojet-General, Sacramento, the NASA Lewis Research Center, and several other customers. Aerojet has sold these commercially. Typically, the units have been used to provide safe test termination involving rocket motors with unstable burning. Several hundred milliseconds of instability can destroy such hardware. Also, the units have been used in conjunction with accelerometers on similar test hardware.

A block diagram is shown in Figure 9. Each element of the three "set" parameters can be individually adjusted to suit test conditions.

There are three basic functions in the CSM. These are: (1) determination of the input level in relation to the desired critical level; (2) determination of the frequency of the incoming signal in relation to the critical frequency; and (3) timing of the interval in which the critical levels of amplitude and frequency have been simultaneously exceeded. These steps are sequentially accomplished by the combustion stability monitor in the order listed above. Signals can appear at the output of the signal level sensor only when the input level exceeds the critical level. Signals can appear at the output of the high-pass filter only when the frequency is above the cutoff value of the filter. Timing action starts whenever a signal appears at the input to the time delay.

Figure 9 - System Block Diagram at Combustion Stability Monitor

Elimination of signals beyond the field of interest is accomplished by the use of an active band-pass filter. This unit provides a roll-off of 12 db per octave below 500 cps and above 9 kc. The response is flat between 600 and 5000 cps.

Because of the action of the signal level sensor, signals will appear at the input to the high-pass filter only when the incoming signal is of large enough magnitude. Signals may also appear because of the action of the series of pulses whose repetition rate corresponds to the frequency of the input signal. The high-pass filter is designed to deliver a signal only when the pulse repetition rate is above the critical rate. The cutoff point must be as sharp as possible.

Filter action is achieved by comparing a pulse whose width is a function of the signal frequency with a standard pulse whose width is set to equal the reciprocal of the frequency at which it is desired to start passing signals. By this method signals come through the filter only when the critical value is exceeded.

To obtain a pulse whose width is a function of the signal frequency, use is made of the bistable circuit. This circuitry switches state every time it receives an input pulse going in the negative direction, or from 1 to 0; it remains at that state until the next pulse is received.

Monostable circuits deliver a pulse when excited by a pulse. The output pulse width is determined by the constants used in designing the circuit, not by the input pulse width.

The techniques described above result in pulses being present at the output of the pulse shaper only under conditions where the incoming signal amplitude is greater than the critical level and where the incoming signal frequency is greater than the critical frequency. The absence of either condition will block the signal from reaching this point.

When a pulse appears, it indicates that a signal with the frequency and amplitude characteristic of instability is being monitored by the CSM. This first pulse could be used to initiate the shutdown sequence. However, engine testing is expensive and unnecessary shutdowns are a waste of time and material. It is necessary, therefore, to have a high confidence level to assure there is a bonafide case of combustion instability. Two steps are taken to increase this confidence level: (1) a time delay is introduced between the first pulse from the pulse shaper and the initiation of the shutdown sequence, and (2) circuitry is incorporated to ensure that the series of pulses from the pulse shaper is continuous with no gaps greater than 3 millisec in the pulse string. The 3-millisec time interval is introduced to prevent a recycle of the timer in the event of jitter, which may occur at the threshold points.

After the required delay period, as determined by the RC network of the timer, a positive voltage will appear at the output of the timer. This voltage is used to drive a transistorized relay. Once the relay is activated, it is latched on through its own contact to the 28v dc supply. In turn, a 28v dc signal initiates the engine shutdown sequence.

Complementary circuitry consists of a unijunction transistor wired up as an oscillator with the frequency and output voltage matching that generated during engine instability. In this way the operation of the control and overall circuitry can be verified.

B. ANALYSIS TECHNIQUES

Analysis experience and techniques are needed in a multitude of disciplines to perform the study proposed. In general, mechanical analysis and flow-induced mechanical analysis are affected by both the plant radiation and temperature environment. Nuclear analysis of the primary system is, therefore, a requisite for predicting long term problem areas. The temperature environment, together with nuclear analysis, indicate thermally stressed areas and the conditions which the instruments must be capable of withstanding.

Materials whether metallic or nonmetallic are affected by the environmental conditions of radiation, temperature, and load. On the other hand material properties must be known in order for problem area predictions to be made in mechanics and material deterioration areas. Support functions of a coordinating nature as input for guidance and continual analysis are also needed in the areas of Safety, Reliability, Quality Control, and Cost.

A functional diagram indicating how the analysis for Phase I of the proposed work will interface and flow is shown in Figure 10.

[(1)e] 1. Nuclear Analysis

The design of hardware to be operated in the immediate vicinity of a reactor may be significantly influenced by the radiation environment. Radiation levels affect material selection and when the levels are sufficiently high, they strongly influence the thermal design. When transducers are involved, the influence of radiation on the signal must also be considered. Some locations around the FFTF involve radiation levels that are sufficiently high to have the preceding effects.

Radiation intensities of these magnitudes are encountered infrequently in power-station systems because of the availability of shielding. The importance of minimizing weight in both the SNAP and the NERVA systems has required Aerojet to develop the analytical tools with which to handle

Figure 10 - A Functional-Interface Flow Diagram

extra-core radiation of such magnitudes. These tools have made it possible to design NERVA pressure vessels with no thermal shields and have provided the detailed information required to design NERVA nozzles. Aerojet's nuclear support in the design of the Los Alamos Scientific Laboratory Phoebus-2 nozzle was such that Aerojet was requested to extend its heating rates to include the pressure vessel as well.

This nuclear background has an obvious application in the Fast Flux Test Facility and was used in FFTF Phase II investigations. Participation in this activity has extended the capability of Aerojet nuclear analysis to include sodium-cooled reactors. Figures 11 and 12 from the FFTF Phase II Final Report show the axial distribution of neutron and gamma-ray radiation in the FFTF. These same techniques could be used to predict the detailed distribution at any position within the system or within a component so adequate thermal analyses and materials investigations could be completed.

Aerojet has an extensive background in projects specifically oriented toward shielding and radiation analysis. This experience is related to the design of ML-1, NERVA, and SNAP as well as to various related efforts.

In addition to the NERVA engine, this program includes a sequence of developmental configurations each of which requires an analytical prediction of its environment. These configurations include the NRX, the NRX/EST, and XE as well as the flight engine. The NRX is a configuration specifically for reactor testing, while the XE is a ground-test configuration with an engine closely coupled to the reactor and separated by a shield. The NRX/EST is a hybrid of these two consisting of a breadboard engine close-coupled to a NRX test. Each of these ground-test engine configurations requires extensive shielding that Aerojet designs and delivers as part of the engine. In addition, predictions of the nuclear environment are required before each test for detailed test planning.

Due to the intense nuclear environment of a NERVA engine, numerous problems are encountered in designing components. These problems

Figure 11 - Neutron Spectra at Three Axial Locations

Figure 12 - Axial Distribution of Gamma Ray Dose Rates - Unshielded

are eliminated or reduced for some components by the use of shielding. For other components, however, the relation to the reactor is such that shielding is not possible. Even these problems can frequently be resolved if the environment can be accurately predicted. Examples of such components include the nozzle and the pressure vessel. Prediction of nuclear-heat-generation rates in these components and specification of the nuclear environment with whatever shielding is necessary is performed by Aerojet for all components as part of the NERVA Program.

Though probably more detailed than the requirements of FFTF, the analyses described here have very stringent accuracy requirements. This experience is, therefore, of value in establishing comparative precision capabilities of various analytical techniques. The design of supplementary shielding is directly related to any shields required by the proposed FFTF instrumentation.

All of the configurations developed in the NERVA Program to date have been for ground testing. The radiation analyses for these systems, therefore, considered all the scattered and secondary radiation resulting from such tests. The execution of these tests, nevertheless, results in two additional considerations: (1) the ability to make measurements with which to evaluate the radiation predictions and (2) the incidence of test-stand contamination from fission products and neutron activation.

The need to develop engine components compatible with the NERVA environment produces a requirement to test materials in a comparable radiation environment, so that the design selections can be made with confidence. The environment of each test is calculated in the course of specifying the test to determine if the experiment will accomplish its objective.

Aerojet is the prime contractor for the SNAP-8 system for electrical conversion. Moreover, the related experience from this program is expanded by additional studies of the system, some of which are specifically related to radiation environment.

In designing the power-conversion system for SNAP-8, Aerojet has had to assure adequate resistance to the radiation environment. Calculations were made to predict the system environment and to establish the shielding requirements of the system. Particular areas of interest were neutron activation, secondary gamma production, and radiation scattering from the protuberant SNAP-8 radiators that will also be present in almost all other nuclear space power systems. An effort is also made to select components that would be least affected by high radiation levels and tests are performed to demonstrate system reliability in the expected environment.

Under contract to the Air Force, Aerojet studied nuclear design criteria for a large aerospace environmental chamber. Reference designs were established for space power reactor systems (fast and epithermal) using various conversion devices (turboelectric, thermionic, thermoelectric). Problems associated with environmental testing of these reactor systems in the induced space environment of the chamber were investigated as a basis for determining the chamber design criteria. Both neutron and gamma radiation scattering analyses were performed assuming single and multiple scattering in order to determine the payload exposure and optimum positioning of the test systems in the test chamber.

These studies of SNAP systems have familiarized Aerojet with the problems associated with radiation analysis of the SNAP systems and provided workable solutions to these problems. As with the NERVA analyses, the specific solutions may not be optimum, but the experience provides a solid basis from which to support the analytical requirements of designing diagnostic instrumentation for the FFTF.

Shielding against shutdown radiation was the primary objective of the ML-1 shield design. A secondary objective was to reduce operational levels insofar as the reactor package weight limitations would permit.

To achieve these objectives, a series of experiments were performed at the Lid Tank Facility of the Oak Ridge National Laboratory in which the proposed shield was mocked up in slab geometry. The detailed arrangement of the selected shield configuration was established as a result of operational and shutdown measurements made at this facility.

In addition to the Lid Tank Experiments, other tests, measurements, and calculations were accomplished to investigate other design characteristics of the ML-1 shield. The dose rate from capture gamma sources during operation and activation sources for shutdown conditions were then calculated using these neutron flux distributions. Removal theory was used to calculate the fast and thermal neutron flux distributions in the ML-1 shield for comparison with the results of the SNG code and Lid Tank Measurements.

ML-1 operational levels and heat-generation rates were obtained using a multi-group, multi-region, gamma ray attenuation code designed for computing gamma ray heating and dose rates in infinite or semi-infinite slab shields. This code was used to calculate the operational levels measured in the Lid Tank Experiment, using source strengths calculated for each region. After it was determined that the calculated results were in good agreement with experimental measurements, detailed calculations were performed on the ML-1 shield.

These analytical and experimental studies of the ML-1 shield design add significantly to the Aerojet background since continued reference to experimental data is the essence of radiation analysis.

Table 1 lists some of the programs available to Aerojet for nuclear analysis.

TABLE 1

NUCLEAR ANALYSIS PROGRAMS AVAILABLE IN AEROJET
(EXCLUSIVE OF PERIPHERAL PROGRAMS)

<u>Point Kernel Methods</u>	<u>Monte Carlo Methods</u>
14-0 and 14-1	Faster
QAD-P5 (Modified)	05R
QAD-HD (Modified)	FMC-N
KAP-V (Modified QAD)	FMC-G

S_n Transport Methods

<u>One Dimensional</u>	<u>Two Dimensional</u>
DSN (Cylindrical, Spherical or Slab)	TDC (r,z, or r,θ)
DTK (Cylindrical, Spherical or Slab)	ODD-K (r,z, or r,θ) (Modified DDK)
DTF-IV (Cylindrical or Slab)	DDK (r,z, or r,θ)
MISPHT (Spherical)	2DF (r,z, or r,θ)
TAPAT TOPIC (Cylindrical)	
MIST (Slab)	

Gamma and Neutron Scattering Methods

GGG - Klein Nishina Scattering (Volumetric and Surface)
 GAMSCAT - Gamma Albedo (Surface Scattering)
 NEUSCAT - Neutron Albedo (Surface Scattering)

[(1)e] 2. Thermodynamic Analysis

The thermal analysis support and coordination for the proposed program will be provided by the Thermodynamics Section of the Nuclear Rocket Operation. This section conducts thermodynamic analysis of the complete NERVA engine system. Typical examples of its tasks include:

- a. Heat-transfer analysis and design of the hydrogen regeneratively-cooled thrust chamber.
- b. Heat-transfer and fluid dynamic analysis of turbo-machinery, valves, regulators and piping components.
- c. Neutron and gamma heating in components surrounding the reactor and special radiation shields external to the reactor.
- d. NERVA engine system thermal analysis when subjected to solar heating and space cooling for typical space missions.
- e. Thermodynamic analysis support to engine testing operations, e.g., NERVA engine test stand operational evaluation and establishment of instrumentation, thermal, and fluid design parameters.

The Thermodynamics Section background as indicated by the above tasks encompasses the type of thermal support that is required for the program. For example, the major thermal support for this program is basically to define those specific areas of the reactor vessel and associated components in which temperature provides a controlling parameter for surveillance and in-service inspection. This thermal parameter can directly or indirectly influence the detection system design depending on the reactor vessel's limiting design criteria, be it a material temperature limit (direct) or an indirect effect of thermal stress. To define these thermal parameters, a good general thermal model is required of the entire reactor vessel system. By means of an existing computer program currently in use in the Thermodynamics Section, a thermal model can be established to provide a detailed thermal map of the reactor vessel and components. The following are brief descriptions of the thermal computer programs established for Aerojet's IBM 360 system digital computer.

a. The Chrysler Improved Numerical Differencing Analyzer (CINDA) program is in production at Aerojet. Many of the analyzer programs in the industry were surveyed and the outstanding features of each, along with many new features, were incorporated into this improved numerical differencing program. This program, although written primarily for use as a thermal analyzer, has great flexibility, contains over 200 subroutines, and can be readily used as a fluid flow or dynamics program. The program's outstanding features relative to thermal analysis are:

(1) The program will accept up to 4095 individual node numbers and 8190 individual conductor numbers.

(2) A variety of numerical differencing techniques is available, including faster techniques that may sacrifice some accuracy but shorten the computation time.

(3) The program is a useful tool for rapidly solving complex thermal and fluid-flow networks, because of its ability to provide essentially the entire computer core for the solution of a problem.

b. The Thermal Network Analyzer program is slower and more limited than "CINDA" for complex thermal problems, but it provides somewhat better service for less sophisticated problems. This program provides a good working tool for routine thermal analyses.

c. The 1040 program is a thermal stress computer program that is typical of several available at Aerojet for solution of stress problems. The temperature distributions from the programs above are used as input to the stress program. The stress programs are discussed in Section III.B.5.

The computer programs discussed above are typical of the type of analytical tools to be used in the proposed program. In addition to these computer programs, various other computer programs are available that apply to thermal analyses of thrust chamber regenerative cooling, special

geometry conduction heat transfer, radiation shape factor calculations, and special thermodynamic process calculations. Technology from these computer programs can also be applied to the surveillance study depending on the development of the thermal model and the specific types of problems determined from this study.

In addition to personnel from the Thermodynamics Section, coordination with thermodynamists at Aerojet's San Ramon and Azusa facilities will round out special capabilities in reactor core heat transfer and fluid flow.

At Aerojet's San Ramon operation, for example, liquid metal heat-transfer rates and associated two-phase flow dynamics have been the subject of numerous experimental and theoretical studies during the past decade. Difficulties were encountered in achieving rated heat-transfer fluxes in NaK-heated systems. Several supporting programs were conducted in conjunction with the SNAP-8 study to investigate possible causes of discrepancies between analysis and experiment. After several years of design, analysis, and test, the heat-transfer rates are now well represented. The knowledge gained in NaK and other liquid metal systems relative to heat-transfer characteristics will be applied as needed in the FFTF thermoplant study. Further details of the Liquid Metal Programs and experience at Aerojet's San Ramon and Azusa facilities may be found in Experience Sections D and E, Related Contracts, and Background Experience, respectively.

The approach to thermal analysis required is similar to the general approach used in most heat-transfer problems: that is, the establishment of a good thermal model. Based on the requirements of the RFP RM5 to survey the entire operating conditions of the reactor, a thermal model will be established from a heat balance to accommodate both transient and steady-state heat transfer from the core to the working fluid and the associated reactor components. The model will contain flexibility for input of significant thermal environmental factors where required. The overall scope of the thermal model will be directed by past experience with nuclear systems in

localizing specific problem areas or critical operating points. These known critical areas will be modeled in detail and, if required, decoupled from the system model. For example, a thermal stress limitation in a component may require defining a detailed thermal map at a specific location within the component. Therefore, a detailed model will be made of that particular component, inputting the system boundary conditions that were determined from the overall system thermal model.

The major purpose of the thermal model is to justify the need for surveillance by determining the governing thermal parameters. These thermal parameters are then used in a stress or dynamic analysis to establish the basis for a monitoring system. In this sense, the thermal model supports the stress and dynamic analysis. Therefore, of major importance to the establishment of the monitoring system is the close coordination, cross fertilization, and exchange between the complete thermal/stress/dynamic analyses. For this reason the thermal model development will be paced generally on the requirements of the stress and dynamic analysis, in addition to the material considerations.

[(1)e] 3. Material Evaluation

During the initial phase of effort a definition of specific areas for surveillance of material changes will be conducted. In addition, parallel efforts appear to be needed in the analysis of special problem areas and material support to instrumentation. The former effort should include radiation damage and corrosion effects, bearing wear measurement, and reactor vessel properties.

Concurrent with the survey in Phase II, the following analyses should be made.

Reactor vessel instrumentation - materials effects
Radiation damage effects on materials

Liquid metals corrosion technology
Liquid metals bearing developments
Radioisotope monitoring in sodium loop transfer
Determination of areas for experimental development

a. Problems and Possible Solutions

The problems expected and possible solutions based on Aerojet experience are discussed below.

(1) Liquid Metal Corrosion

Corrosion by sodium involves mass transfer of Ni, Cr, Mn, and other elements from the structural materials, as well as from the fuel elements and reactor core materials. A small bypass line from the hot leg of the sodium loop could be passed through a shielded area where cold crapping allows for the deposition of Fe-59, Cr-51, Mn-56, and Co-58, which will build up in the trap when corrosion rates are high.

Also, fission product release to the coolant could be determined when the general level of activity in the sodium is above normal.

Plugging meters have been developed that indicate when the total dissolved metal content in the sodium is high, so that excessive corrosion deposits will occur in the cold end of the loop.

Oxygen content of the sodium can be monitored by periodic sampling or by development of other techniques, such as proton back-scattering or by a tantalum or zirconium wire resistivity technique. Oxygen content of the sodium must be maintained at a low level (< 10 ppm) in a long-life system.

(2) Self-Welding of Materials in Sodium

Movable parts may be subject to self-welding, which is a serious problem relative to valve seats, control rod systems, etc. A vibration damping on movable components can indicate when self-welding is proceeding.

(3) Bearing Wear in Pump Bearings

Vibration detectors selected for frequencies characteristic of bearing problems may indicate pump problems in the early stages of wear. Also, noise level indicators in specified locations are useful.

(4) Continuous Creep Detector

Expansion due to creep of the reactor vessel and the highest temperature leg of the primary loop may be detected by a diameter or a circumference monitor device, which will indicate small diameter changes during operation at temperature. Other dimension indicators located in the pumps may be desirable.

(5) Crack Propagation (Other Than SWAT)

Detector for sodium vapor (or Na_2O) can be considered for continuous monitoring, in addition to the radioactivity monitor in the atmosphere. Continuous or intermittent vacuum sampling of the gas outside the reactor vessel and in the pipe tunnel around the primary loop can be accomplished.

(6) Tube Burst Test

Burst test specimens designed to indicate the stress rupture life of loop materials, or of cladding materials, can be immersed continuously in the sodium to evaluate the metallurgical effects of corrosion, mass transfer, and nitrogen or carbon transfer in the primary loop. The immersed tubes can be filled internally with sodium and pressurized through a capillary tube system. The flow and pressure required for deformation of a given tube specimen will indicate metallurgical changes. A number of tubes built into the system will allow periodic tests.

(7) Ductility Test

Control specimens can be stored in an accessible area of the primary loop, where a remote system can extract them for testing to evaluate changes in ductility of the structural material due to the combined effects of radiation, sodium, and the transfer of interstitial elements in the loop.

(8) Radiation Damage

Consideration of possible detrimental thermal neutron radiation should be made for valves and other components that are near the reactor vessel. Radiation induced ductility and stress rupture strength losses can be detected in stainless steels at 1200°F after thermal neutron exposures of 10^{18} nvt; however, serious ductility or strength losses will not occur until the exposure outside of the vessel would be between 10^{17} and 10^{18} nvt in 30 years. Precipitation-hardened nickel base alloys, on the other hand, can be subject to significant losses in high-temperature stress rupture life and in tensile elongation after thermal neutron exposures as low as 10^{15} nvt; therefore, the use of such alloys should be limited to locations where predicted thermal neutron exposures will be less than 10^{15} nvt, or severe design limitations could be encountered.

Fast-neutron damage will be insignificant to metals or alloys operating between 800°F and 1200°F, because the integrated exposure should be below 10^{18} nvt, and atom displacement damage will be partially or totally annealed at these temperatures.

Generally, the effects of atom displacement damage from gamma-induced photoelectrons are ignored because of the much larger damage incurred by fast or thermal neutrons. However, the very large integrated gamma exposure of 2.5×10^{13} rads or about 3×10^{22} photons/cm² in 30 years can result in an appreciable number of atom displacements, and this source of damage to mechanical properties must be considered for any materials that operate below 800°F.

Extensive materials testing has been performed at Aerojet. Additional discussion of the Aerojet radiation-effect capability and test program can be found in the following section (Section III.B.4). The work has been primarily on structural materials in extreme nuclear radiation and temperature environments. Irradiation and testing have required the development of unique in-pile mechanical and electrical test techniques. Most tests involved mechanical properties; however, a few tests included thermal and electrical conductivities, which required the resolution of problems relative to obtaining reliable radiation-resistant instrumentation.

The radiation embrittlement of high-temperature materials due to helium created by transmutation has been investigated in the solution-hardened materials AISI 347, Hastelloy X, and Inconel 625 at test temperatures as high as 1540°F and for thermal neutron fluences of 10^{19} nvt. Similar studies have been made in the high-strength precipitation-hardened alloys Inconel 718, Waspaloy and Rene 41. These latter alloys are more sensitive than the solution-hardened alloys.

b. Pertinent Experience

The following experience is especially pertinent to adequate material evaluation.

(1) NERVA

NERVA corrosion activities involved evaluation of pitting, intergranular corrosion, and stress corrosion cracking of nuclear shield components in liquid bismuth lead eutectic alloy. Changes in strength ductility, microstructure, and crack propagation under stress in the liquid metal were evaluated. The presence of dissolved oxygen in the liquid metal was found to have a controlling effect. The possibility of dissimilar metal electrogalvanic effects in bismuth-lead were indicated.

(2) Phoebus II Nozzle Program

The high temperature conditions and the severe heat flux and radiation environment required for the Phoebus II nozzle required new materials technology for the large nickel-base alloy forgings. New and improved methods of instrumentation were employed throughout the fabrication, automatic welding, and ultrasonic examination, as well as during qualification tests and in the chemical simulation firing of the nozzle.

(3) SNAP-8

A complete literature review and compilation of technology of liquid metals, including corrosion, was performed for the SNAP-8 program.

Other evaluations were:

(a) Corrosion and solubility of structural materials in liquid rubidium for proposed space power systems.

(b) Evaluation of carbon transfer embrittlement in the sodium loop.

(c) Evaluation of solubility of refractory metals in the sodium loop.

(d) Measurement of corrosion effects due to dissimilar metals in liquid-metal heat exchangers.

(e) Failure analysis of tube welds in liquid-metal heat transfer systems.

(f) Purification of liquid sodium, sodium-potassium, and mercury.

(4) SPUR - (SNAP-50)

Studies of refractory metal systems at high temperatures (above 1400°F) for liquid-alkali metal loops and heat exchangers were conducted. Development of a tube burst-test for evaluating materials properties in an alkali metal environment at high temperature was completed. Evaluation was made of creep rates in sodium and in lithium at high temperatures.

(5) Thermoelectric and Thermionic Power Generation Technique using Liquid Metal Heaters.

Evaluation was made of corrosion in thermionic emitters. Testing was conducted of refractory oxide insulators in contact with liquid-alkali metals at high temperatures. Analysis was made of corrosion effects in thermionic emitters heated by alkali metals.

[(1)e] 4. Radiation Effects

Radiation environments affect materials and instrumentation to various degrees. Because of the complexity of radiation effects, nuclear power plant designers may not possess current knowledge about these effects

to judiciously select materials and instrumentation for a particular application. The problem, therefore, becomes that of making certain that the materials and instrumentation sensing elements will perform safely and reliably in the radiation environments for which they have been selected.

Aerojet's approach toward solving this problem is to critically review the proposed plant designs developed by the planners. To do this, radiation effects specialists will study the selected materials and sensing elements to determine if they will be suitable for the specific application. Aerojet's past radiation-effects experience with NERVA materials and instrumentation will serve as a foundation for this review. From the study, the specialists will be able to determine the critical instrumentation items and materials and establish their probabilities for safe and reliable operation over their projected life spans. Substitute instrumentation and materials will be recommended whenever experience indicates that the prime candidate material or instrumentation will not perform to design performance expectations. Alternatives will be selected on the basis of safety, reliability, and cost.

If an alternative instrumentation element cannot be substituted satisfactorily and development becomes necessary, NERVA experience in planning and executing radiation effects tests for component development again is available to optimize testing and minimize costs. Previous testing of pressure transducers of various types, for example, established their inherent weaknesses in a radiation environment. These findings subsequently led to the development by Aerojet of a strain-gage type-pressure transducer, having minimum mass, that has proven its high reliability during actual reactor tests.

Aerojet's experience in radiation effects is not merely analytical, but also that of actual design, development, and radiation testing of materials and components in the NERVA program. Tests have been conducted for several years in the Ground Test Reactor and the Aerospace Test Reactor.

Table 2 summarizes the combined nuclear testing performed through the past year. The number of units tested, as well as the number of tests performed in each component development program, are also shown. The tests varied in complexity from static irradiation and subsequent post-irradiation testing, to dynamic tests in which the components were tested under design load and operating conditions. In addition to these tests, many components have been incorporated into nuclear rocket reactor tests and have performed successfully.

As of this past year, in four major tests, over 1400 structural material specimens and 400 organic specimens have been irradiated and tested. Typical stress-strain plots and data tabulations depicting the effects of irradiation on various mechanical properties (including yield strength, ultimate strength, shear strength, area reduction, and elongation) have been published. Table 3 summarizes some of the materials tested.

The testing of materials and components in combined environments has contributed to the technological development of an operational nuclear propulsion system. The activity has resulted in the design of instrumentation and mechanical components, and the selection of candidate materials that have a potential for meeting the requirements of a flight engine. Future combined environmental testing is contemplated. Future work will be directed towards additional development, evaluation, and qualification of instrumentation and controls systems, mechanical components and systems, and the acquisition of data for the designer on the effects of higher radiation levels on the properties of materials. These efforts will help provide the basis for the high reliability required in the final design of the flight-rated nuclear-powered vehicle.

TABLE 2
SUMMARY OF COMBINED NUCLEAR TESTING
PERFORMED THROUGH THE PAST YEAR

<u>Component Description</u>	<u>Units Tested</u>
<u>Diagnostic Instrumentation</u>	
Pressure Transducers	26
Accelerometers	32
Strain Gages	86
Resistance Temperature Transducers	60
<u>Materials</u>	
Structural Metals	1493
Organics	459
Reactor Materials	1
<u>Engine Components</u>	
Tank Shut-off Valve	1
Turbopump Bearing/Retainers Assembly	5
Metal Seals and Flanges	3

TABLE 3
LISTING OF SOME OF THE TESTED MATERIALS

<u>Metals</u>		<u>Organic Materials</u>
<u>Material</u>	<u>Material</u>	<u>Material</u>
Stainless Steel	Nickel Base Alloys	Armalon
A-286	D-979	TFE-405-C-116
347	Udimet 630	TFE-405-L-112
347C	Hastelloy X	FEP-510-L-128
301	Hastelloy C	Teflon
303 Se	Inconel X 750	FEP
440 C	Inconel 713 C	SP-3 (Polyimide-MoS ₂)
410	Inconel 718	Polyimide-MoS ₂ -Bronze (Various Proportions)
Aluminum Alloys	Inconel 625	
6061-T6	H-Monel	Polyimide Glass Cloth (Reinforced)
7075-T6	Inconel 718	
7039-T61	Waspalloy	
2219-T6	Titanium Alloys	
A356-T6	Ti-5, Al-2.5 SnELI	

[(1)(10)e] 5. Stress, Strain, and Vibration

Aerojet has a complete capability for the analysis of stress, displacement, and vibration in both thick and thin walled structures and of piping and space frames. It also has a capability in the thermal stress analysis field (the structures section uses inputs from the thermodynamics heat transfer section for this purpose) and in mechanical stress analysis (temperature-dependent material properties are used). These capabilities, which were developed over the years, in connection with the design of rocket engines and nuclear reactors and plants, have now largely been computerized so that the effects of design variations do not require a complete iteration of the design process for evaluation.

Strong structural analysis capabilities have also been developed in the field of composite materials (such as filament-wound pressure vessels), infiltrated materials (such as silver-infiltrated tungsten), rubbery materials (such as solid propellants) containing oxidizer particles, and anisotropic materials such as graphite. Stress-analysis techniques are embodied both in Aerojet structures manuals and in NERVA computer programs manuals. The structures section has developed the finite element method for the accurate stress analysis of continuous structures. Experimental stress-analysis techniques used at Aerojet include photoelastic and photostress methods. The photoelastic method has also been successfully applied to the determination of three-dimensional thermal stresses.

Based on the stress analysis of a structure, decisions are reached concerning the best location at which to mount instrumentation during proof testing or operation. Usually such instrumentation is mounted in critical areas, where the overall analysis shows that the stresses or displacements will be highest and the theoretical margins of safety lowest. Strain gages of biaxial and rosette type are commonly employed on pressure vessels. Their outputs are now fed directly to a computer for determination of the associated stresses. Strain gages, for strains to 3%, have been used for monitoring the

strains in filament-wound pressure vessels. Displacement transducers have also been used for measurement of the growth or angulation of structures under test.

Radiation-resistant gages have been used to determine mechanical strains induced by a thermal gradient and to determine vibratory strains in delicate components during operation of a high-altitude simulating reactor exhaust duct. Displacement gages have been used in the same facility to monitor the angulation of bellows in a high-temperature (1400°F) steam line. Aerojet has developed the use of embedded strain gages for the determination of internal stresses in composite materials and has also developed special techniques for the determination of mechanical strains (exclusive of thermal-expansion strains) at temperatures up to 3000°F.

The Structures Section is also responsible for the placement of accelerometers and for assuming that the design of the accelerometer mounts is consistent with the range of frequencies to be evaluated.

The Structures Section establishes the limits of the structural instrumentation that is used and is responsible for correct ranging. Test results from accelerometers are evaluated and are frequently also used for deriving rough estimates of displacements in locations where deflectometers are not installed (e.g., on the turbopump of the NERVA reactor).

Aerojet has a wide range of experience on noise problems associated with rocket engines and with the correlation of noise levels with flow velocities, gas composition, and rocket power. Experience gained on the KIWI Nuclear Rocket is currently being extrapolated to the noise environment of the NERVA reactor: noise levels of this reactor are also being monitored during the preliminary and cold-flow testing phases for extrapolation to "hot-firing" conditions. Stresses in thin panel structures due to random acoustic loading will be re-evaluated based on prevalent noise levels to give assurance that fatigue as a mode of failure will not be a problem either in the NERVA

reactor or the test facility. Aerojet also has developed a special acoustical transducer which has been used for the monitoring of launch acoustics at Cape Kennedy. As with accelerometer data, acoustical data is also analyzed to determine the sources of particular noise levels observed and to initiate corrective action where applicable.

A computer program which was developed by Aerojet for the measurement of stresses and strains in dams, buildings, and other thick walled structures may be uniquely suited to the continued surveillance of the pressure vessel. This method of displacement/strain measurement has been proven on the Oroville Dam in California where permanent instruments are embedded in the dam to measure stresses as a means of verifying structural integrity. Aerojet's finite-element structural analysis is an outgrowth of this program.

Aerojet has devised a three-dimensional finite-element analysis which determines displacements of thick-walled structures in three planes. This program appears ideally suited to the analysis of large pressure vessels.

There are three vibration problems which may be observed in the FFTF sodium coolant system: (1) structural vibration; (2) hydraulic vibration; and (3) hydro-elastic vibration. The structural vibration problem is characterized by the existence of a high-gain (lowly damped) vibration mode of the structure which is "driven" by a source of vibrational energy such as a pump. The hydraulic vibration problem involves the acoustic oscillations of the fluid in long transmission lines. A "waterhammer" oscillation in a fluid piping system, or a "hard start" in a liquid rocket engine, are good examples of transient hydraulic vibration problems. Finally, the hydro-elastic problems are caused by an interaction of the structural response and hydraulic (acoustic) response of a complex system.

The dynamic analysis of a coolant feed system (a complicated array of interconnected fluid transmission lines, cooling tubes, and pumps) is made complex by the interaction of these hydraulic elements. Two basic

methods which may be used in the analysis of wave propagation through fluid lines are: (1) time-domain analysis; and (2) frequency-domain analysis. Frequency-domain analysis is more expedient for the steady-state dynamic analysis and data-analysis techniques to be applied for the FFTF.

A complete analytical model employing electro-mechanical-acoustical impedance techniques and matrix methods is proposed to compare periodically monitored data with the normal response of the system. The FFTF coolant system can be treated as an acoustical-impedance network in terms of fluid mass (inertance), compressibility (capacitance), and resistance. Due to the direct analogy to electrical impedance networks, a complete set of system equations defining dynamic interaction can be obtained. These analytical impedance techniques have proved effective in handling dynamic problems on large fluid systems. Aerojet control dynamicists have developed and applied these techniques to define and eliminate feed-system combustion-process-coupled instabilities for the Apollo, Transtage, and Titan IIIM systems. Fluid stabilization devices (e.g., acoustic filters in the form of stand pipes and Helmholtz resonators) have been successfully designed and tested. Recent consulting efforts on Saturn "Pogo" stability problems have resulted in a detailed study of "lossy" feed line and gas injection stabilization concepts. These concepts might prove useful in hydraulic vibration problems in the FFTF.

Aerojet has extensive data analysis and reduction experience for periodic, transient, and random noise data. Tape-recorded dynamic data can be digitally reduced with existing computer programs. Transfer function analysis may be preformed with two programs: (1) Job 2907, which accepts random inputs such as random noise; and (2) Job 2909 which accepts deterministic function inputs such as a step, sine, or impulse.

A transient analysis digital computer program, which has been under continuous use and development at Aerojet since 1957, is available for use in the analysis of waterhammer problems. The techniques used in the

frequency response analysis of acoustical networks have been programmed in specialized subroutines and used in other programs, but these are easily adapted for use in the FFTF analysis.

The FFTF coolant system could be periodically excited with a known function and the system response be monitored and recorded on tape. The test data could then be processed through the Aerojet hybrid spectral-analysis system and the results compared to results expected for normal operation. These may include ratios of responses (or transfer functions) and power spectral densities. Depending upon the parameters operated on a shift in the response functions may indicate problem areas in the system.

Through the NERVA program, instrumentation has been developed which will monitor flow and mechanical vibrations under severe radiation and thermal environments. Remotely operated systems have also been developed to monitor instrumentation.

The Structures Section has been required, for example, to devise accurate methods of measuring vibration levels on the NERVA technology engine resulting from propellant flow, from the turbopump, from the exhaust nozzles, and from external sources (e.g., seismic motion of the test stand and ground shock into the stand from underground nuclear blasts).

The primary structural problems associated with the design of a nuclear power station are the same as those associated with the NERVA program. High reliability is of major importance in both cases: the only real difference being the length of service required for testing. NERVA engineers have been called upon to analyze and test large valves for the ATR program in Idaho Falls, Idaho because of their familiarity with valves and plumbing of this type.

The following list of computer programs is a summary of structural analyses as applied to the field of stress and dynamics. The listing is not intended to be complete, but rather a representative selection of those which receive general usage.

1. Bending Analysis for Plates (Finite Element)
2. Finite Element Analysis of Solids with Non-linear Material Properties
3. Finite Element Analysis for Cylindrical Shells and Plates
4. Shells of Revolution Subjected to Nonsymmetrical Loads
5. General Torsion Analysis
6. Piping Flexibility Analysis (Space Frame Structures)
7. Dynamic Analysis Program 998
8. Dynamic Analysis Program 1042
9. Plastic-Elastic Thin Shells of Revolution
10. Structural Analysis of General Three-Dimensional Frameworks for Static Loads

[(1)e] 6. Reliability and Quality Control

The reliability and quality control tasks to be accomplished in this research and conceptual study program will center around a comprehensive reliability assurance program that is considered essential to the development of an adequate instrumentation and surveillance system for the FFTF.

The objective of the reliability assurance effort during the course of the study will be to ensure development of a surveillance instrumentation system capable of meeting the stringent environment of a liquid-sodium cooling system in a nuclear environment. However, liquid-metal flow requirements, the high temperature involved, and the presence of a fast breeder reactor will pose difficult reliability and quality control requirements for the system.

Aerojet believes that the basic reliability objective during the study phases can best be accomplished through a comprehensive malfunction detection analysis (MDA). This analysis is accomplished in four parts as follows:

- Component failure mode enumeration
- System (subsystem) failure mode enumeration
- Surveillance instrumentation requirements
- System (facility) consideration

The malfunction detection analysis will be accomplished on the FFTF drawings and sketches as provided by Battelle-Northwest. Examples of each of the four parts are:

Component Failure Modes - Sodium system piping or valve burn-throughs, flange or weld leaks, erratic valve responses, electrical circuit failure, erratic reactor performance.

System Failure Modes - Sodium or hot-gas leakage, failure of cooling system, excessive reactor temperatures.

Surveillance Instrumentation Requirements - Temperature and pressure displays, vibration and displacement displays, visual and nondestructive testing (NDT), acoustic and noise analysis, and automatic shutdown features.

System Consideration - Redundant instrumentation and control features, redundant shutdown systems, automatic switching systems, visual and NDT limitations in nuclear (remote handling) areas, continuous-versus-sampling aspects, and facility - instrumentation interfaces.

The MDA will be submitted to the analysis group as part of the analytical studies package for Phase I activities. As can be seen, considerable knowledge of the FFTF design, preferably in the form of a modes-of-failure analysis (MFA), will be required in order to accomplish a comprehensive MDA.

During Phase II, the MDA will be brought up to date as a result of the instrumentation and inspection methods survey for input into the conceptual design and further studies. These reliability activities during Phase II include a MFA of the instrumentation and NDT methods selected. Included in the MFA are such quality considerations as inspectability, limited-life items, spare-parts requirements, and remote-readout features. The MDA and MFA thus form a package for design review purposes in the conceptual design finalization efforts.

Aerojet's past and present programs have afforded the company extensive experience in projects requiring highly effective quality-assurance programs. The term "quality-assurance" refers to all reliability and quality actions: quality control refers to such management functions as inspections, audits, and control of nonconforming action. Aerojet's existing quality-assurance system complies with government and military requirements and is continuously audited by permanent on-site Government representatives. Quality control programs are typified by NASA NPC-200-2, MIL-Q-9858A, and MIL-Q-21549A. Reliability requirements are represented by NASA NPC-250-1, MIL-R-26674, and MIL-STD-785.

The following represent special cases in which a combination of unique conditions or unusual requirements imposed special quality-assurance requirements that were met successfully.

a. SNAP-8

The instrumentation and surveillance experience gained in depth on the SNAP-8 program is particularly pertinent to the proposed

program because it involves liquid-metal technology and a nuclear environment. Special quality-assurance actions were found to be necessary that were unique to this program. These included the development of very detailed welding procedures for liquid-metal test facility lines, the development of methods of handling and assembling parts in an unusually clean environment, and the application of laboratory techniques to a facility installation and operation.

b. NERVA

The NERVA program includes several cases in which a nuclear environment and a hot-gas environment are superimposed on an instrumentation and surveillance system with high reliability. For example, a NERVA valve operates in a nuclear environment as a mechanism tolerating a neutron flux of 10^{13} n/cm² sec. The NERVA turbopump offers a similar example of a heated/cooled nuclear environment. The severe temperature differential and the demanding requirements in operating over a wide range of conditions are evident. The Phoebus nozzle is another instrumentation and surveillance system which was developed for nuclear and cryogenic use.

The E-MAD and ETS-1 facilities employed at NRDS in the NERVA program required the application of full quality-assurance requirements to complex experimental facilities in which advanced piping flow systems, remote handling equipment, and extensive and very complex instrumentation and surveillance systems were required to operate in nuclear environments. Experience resulting from the design and activation of these facilities gives Aerojet specialized experience in effectively applying instrumentation and surveillance quality assurance to unique nuclear experimental facilities. In these efforts, the requirements for the facilities and the equipment to be used were defined and a special quality-assurance evaluation was conducted prior to acceptance of the facilities and equipment. Also, Aerojet experience as a user of these facilities provides a unique specialized background that will be beneficial in identifying potential critical items requiring quality-assurance attention.

c. M-1 Turbopump

The M-1 turbopump is an example of large, complex hardware built by Aerojet requiring a sophisticated instrumentation and surveillance system. The turbopump is 6 feet long and more than 2 feet in diameter and can pump hydrogen and oxygen at a high flow rate. The building of very-close-tolerance components that must be able to operate in a sophisticated piece of hardware at cryogenic temperatures (after taking the thermal shock of transition from room to a very low temperature) while tolerating an adjacent turbine operating at 1000°F, represents very close quality control.

d. Minuteman Second Stage

The Minuteman second-stage motor represents a most-advanced operational solid-fuel motor. It provides an array of examples that require unusual quality-assurance approaches although not directly associated with an instrumentation and control system. Since the motor has to meet a 10-year storage life with no degradation in performance, some unusual quality-assurance methods were required to demonstrate system adequacy. Every element of this unit from raw material through final assembly is controlled. Some of the components and their specific requirements are: (1) the nozzle, a composite inorganic material with a tungsten insert, operating at gas temperatures to 6000°F; (2) the pressure vessel, constructed of very-thin-drawn titanium and operating at a very low safety factor (i.e., no flaws can be tolerated in the pressure vessel at any stage); (3) hot-gas lines and valves in the thrust-vector-control system, operating at 2200°F and capable of withstanding extensive thermal shock; and (4) propellant, a very-high-performance type that represents a hazardous operation throughout the manufacturing process. That the quality-assurance system employed by Aerojet was effective in this program is illustrated by the record of 86 successful firings for 100% observed reliability.

e. Idaho Nuclear Corporation - Quality Assurance Manual

Aerojet-General recently completed the Quality Assurance Policies and Procedures Manual to delineate the policies governing the quality-assurance system at the Idaho Nuclear Corporation. This manual establishes the quality system and organizational relationships to "provide those systems and functions required to establish compliance with quality systems requirements contained in Atomic Energy Commission and other Government Publications, and assure conformity of end-use material to quality stipulations contained in applicable design drawings, specifications, and purchase contracts."

[(1)e] 7. Safety Analysis

In Aerojet's nuclear and space-oriented programs (e.g., TITAN, Army Gas-Cooled Reactor Systems Program (GCRE/ML-1), SNAP-8, and NERVA) safety analysis and evaluation have provided extensive support in the design, development, manufacturing, testing, and operation phases. For example, in the NERVA program the initial facility and system design and the conceptual design requirements are reviewed by the safety staff, and necessary safety criteria incorporated. Each progressive phase of the design effort is also reviewed from a safety standpoint, and, as warranted by particular design features, special precautions and specific safety requirements are factored into the overall design effort to establish limits, boundaries, and conditions for safe operations.

In addition, a safety evaluation of test operations is conducted by the safety staff. It consists of a detailed evaluation of the particular test article (e.g., reactor system or engine assembly), its related systems and equipment, and the entire test operation. The evaluation relies heavily on a mode-of-failure analysis which is a systematic study of each critical reactor/engine system or related facility system in terms of the reliability and/or failure mode of the individual components. The safety evaluation is also dependent upon malfunction analyses of the overall test

system. The malfunction analyses are run on an analog computer utilizing programs developed to simulate the temperature, pressure and flow profiles, and other operating characteristics of the NERVA engine.

The type of safety review, analysis, and evaluation support as described above can be made applicable to the surveillance instrumentation requirements studies for the FFTF. Results of pertinent studies and analyses (e.g., materials, stress, fluid dynamics, mode-of-failure, and malfunction) and the design specifications relative to the FFTF piping and pressure vessel system can be factored, from a safety standpoint, into the definition of instrumentation requirements. Accordingly, applicable components of the FFTF system, wherein a malfunction or failure will have critical effect on the safety of personnel and operations will be given primary concern.

An appreciation of the extensive experience and participation that the Aerojet safety staff has can be easily obtained by the following listing:

a. Hazards Evaluation Reports

(1) Final Hazards Summary Report for the ML-1 Nuclear Power Plant, AGN Report IDO-28560, Vol. 1, November 1962.

(2) Nuclear Safety of Advanced Nuclear Space Power Plants, Non-boiling Lithium-Cooled Reactor, AGN Report TP 76, October 1963.

(3) Assessment of Explosion Hazard, Downey Plant Report DE-64015, Vol. 1, January 1964.

(4) Operational Safety Evaluation of ETS-1 Complex, Von Karman Center Report R-2316, October 1962.

(5) RIFT Safety Review Program - NERVA System Description, Von Karman Center Report R-2421, November 1962.

(6) Destruct System, Guided Missile, Wing VI - Safety Requirements and Procedural Information for Handling, Storage, Installation, and Removal, Solid Rocket Operations Report STM-160, March 1964.

(7) Reactor Hazards Evaluation - AGN 201 Reactor, Report AEC-9.

(8) Reactor Hazards Evaluation Report and Site Survey for the AGN 201 Nuclear Reactor, AGN Report 4, May 1956.

(9) Hazards Evaluation for Nuclear Merchant Ships, AGN Report 18, February 1957.

(10) Hazards Summary Report for AGN 201 Reactors, AGN Report 23.

(11) Reactor Hazards Evaluation Report and Site Survey for the AGN 211 Nuclear Reactor, AGN Report 26, October 1957.

(12) Master Plan Study for the Army Reactor Experimental Area, AGN Report IDO-29522, 12 May 1958.

(13) GCRE Hazards Summary Report, AGN Report IDO-28506, December 1958.

(14) Preliminary Hazards Summary Report for the ML-1 Nuclear Power Plant, AGN Report IDO-28537, April 1959.

(15) Nuclear Nitrogen Fixation Reactor, Micro-Loop Safeguards, AGN Report 3037, June 1959.

(16) Aerojet Shielding Test Facility (ASTF) Hazards Summary, AGN Report 3061, December 1959.

(17) GCRE-1 Hazards Summary and Addendums I and II, AGN Report IDO-28506 (under Contract AT(10-1)-880), February 1960.

(18) ETS-1 Facility Safety Report, AGC Nuclear Rocket Operations Report RN-S-0378, July 1967.

(19) Engine Maintenance Assembly and Disassembly (E-MAD) Facility Safety Report, AGC Nuclear Rocket Operation Report RN-S-0394, May 1967.

b. Typical Nuclear Analysis Reports

(1) Preliminary Report on Neutron Induced Activity in the NERVA Engine Components, REON Report RN-S-0135, June 1965 (CRD).

(2) Nuclear Analysis in Support of the Phoebus-2 Nozzle Program, RP-SR-0001, (Volume II), June 1965 (CRD).

(3) Preliminary Report on the NERVA Radiation Environment, RN-S-0133, March 1965, (CRD).

(4) Preliminary Report on Nuclear Radiation Heating of Components in the NERVA Engine, April 1965 (CRD).

(5) XE Engine Shielding Design, RN-TM-0179, April 1965.

(6) NRX/EST Evaluation of Engine System Component Radiation Environment, RN-TM-0188, June 1965.

(7) A Transport Theory Analysis of a Gaseous Core Concept, RN-TM-0190, May 1965.

[(1)e] 8. Costs

As an integral part of the analysis for an instrumentation and surveillance monitoring system, cost is a major evaluated-variable which must be considered. The cost estimate of a particular transducer, for example, rests with the engineer considering the use of that instrument. However, the cost analysis of several transducers to perform a similar function includes their effectiveness and an evaluation of alternatives and rests with management.

In the usual manner, the costs, performance, and alternatives must first be evaluated at the working level and then integrated into the overall program for the best advantage to the government. Aerojet has had much experience in fiscal control, program cost analysis, and optimization of costs (see Section IV.B of this proposal). It is the optimization area that must be considered here because it is the constraints of objectives, safety, and reliability that must be weighed.

During the development recommendation and conceptual design phases of the study, consideration will be given to initial, operation, and maintenance costs. Additional trade-offs will be made between life expectancy, acquisition, and handling costs. This work will interface with the safety and reliability support functions and the instrumentation and system requirements needs.

[(1)(10)e]

C. PARAMETER INVESTIGATION

The parameter investigation involves the suitability of applying instrumentation to measure changes in material with time. These changes may come about through severe environmental exposure which can be in the form of radiation or corrosion damage and stresses and strains due to loads affected by temperature, displacement, and vibration. Another change in material can come about through poor design and workmanship of component parts. In either case, instrumentation must be devised which can provide enough suitable diagnostic information for interpretation. The instrumentation inspection modes usually are categorized by the physical characteristics of the implanted or passive signal, or by the method of inspection itself. Table 4 lists the methods for which instrumentation are needed. Aerojet has accumulated an extensive background of experience in the application and uses of surveillance and in-service inspection techniques for pressure vessels and components of widely varying sizes, shapes, and materials. The inspection techniques examined include on-line gamma scintillation, traversing ultrasonic, fixed probe ultrasonic, acoustic emission, and stress-wave emission.

TABLE 4
METHODS OF INSPECTION

Ultrasonic Inspection	- Active Instrument Signal
Vibration Measurements	- Passive Instrument Signal
Acoustic Wave	- Active/Passive Instrument Signal
Displacement Method	- Passive Gage Signal
Noise Analysis	- Active/Passive Signals
Visual Method	- Active Instrument

1. Application Philosophy

Aerojet has demonstrated a capability of applying instrumentation to the measurement of those parameters necessary to the diagnosis and control of complex nuclear systems. This capability has most recently been

demonstrated in the NERVA and SNAP 8 development programs. The approaches which have produced success in instrumentation application areas have been used both on the test article and in the facilities supporting the article tests. These approaches and some examples of instrumentation similar to those for use on FFTF are discussed below:

a. Application Approach

It is important to determine in some detail exactly what measurement is required. In some cases, for example, strain is to be measured: in other cases, creep is to be measured. It may also be that the measurement requester is actually seeking something else and has assumed that strain is the way of obtaining what he seeks. It must, therefore, be determined what must be provided. A clear statement of the problem is required before an intelligent attempt can be made to meet the requirement.

The required accuracy of the measurement must also be determined. This is vital or funds may be wasted trying to meet an impossible or arbitrarily rigid accuracy requirement. It is important that the measurement requester determine (on the basis of the uncertainty of all the other variables used in his analysis) a realistic uncertainty requirement for the particular measurement. It may be that the need for accuracy exceeds any realistically achievable transducer performance. In that case, other ways of obtaining the desired information must be sought.

The operating life of the transducer must also be determined. Long-term exposure to radiation and/or high temperature causes drastic changes to most transducers. It is necessary, therefore, before embarking on transducer development to know the lifetime requirements and whether or not the accuracy requirements can be relaxed as a function of time.

b. Environment Approach

The environment in the area surrounding the measurement must be known. It is necessary to know the radiation levels, the temperature environment, the existence or absence of severe vibration, and any other environmental factors that could conceivably effect the performance of a transducer.

It has been Aerojet's experience on the NERVA program that picking the worst expected environment and attempting to develop a transducer to meet the highest accuracy requirements in this environment is generally a wasteful approach. It turns out that in many cases the most economical solution is a number of solutions. As an example, strain gages used on NERVA are broken into different categories depending upon the material to be instrumented and their temperature ranges. This approach significantly improves the measurement uncertainty. In considering the installation, environment, and measurement requirements, it may be possible to achieve a solution which meets all the measurement requirements and yet does not require a special transducer.

Pressure measurements on the NERVA program have been made using remotely located "off-the-shelf" transducers while the actual engine-mounted pressure transducer was being developed. Relatively high-frequency response, with pressure-sensing lines 20 to 30 feet in length, was possible using "infinite" line techniques. An engine-mounted transducer is required for a flight engine because of simplicity and ultimately greater reliability, but throughout the engine development program essentially all pressure measurement requirements were met with these remotely mounted transducers. It is felt that the application of these measurement engineering techniques can result in a significant reduction in requirements for new transducers. Aerojet expects that a measurement engineering study will result in sets of requirements which can be satisfied by relatively simple extensions of existing transducers and transduction techniques.

2. Instrumentation and Inspection Examples

a. Strain Transducer Development

Aerojet has investigated LMFBR strain measurement requirements sufficiently to suggest the development of a transducer for the measurement of strain on the external sodium lines. It appears that the variable to be measured is creep rather than strain. There appears to be no strain gage currently in existence or even remotely possible that can accommodate the extreme elongation during creep. It is believed, therefore, that displacement transducers should be used to make this measurement and that they can be attached to the lines by brackets to permit access for replacement or adjustment. The linear variable differential transformer (LVDT) has essentially infinite resolution and can be obtained in any desirable range and, with proper design of the installation, can manually be re-zeroed periodically to further improve resolution. Such devices have ranges as low as 0.003-inch full scale and can be provided in any range through several inches, whereas strain gages with ranges in excess of 0.006 inch are rare. The great elongation of the stainless steels under constant load seems to exclude strain gages from consideration. Aerojet proposes, therefore, the development of an LVDT with an appropriate bracket design to meet the requirements for these measurements.

b. Vibration and Acoustic Measurements

The term "vibration" is used herein to refer to periodic motion of a physical body about an equilibrium point. The term "acoustic stimulus" is used in its broadest sense to describe compressional waves in either fluids or solids, whether audible, ultrasonic, or subsonic.

Either vibration measurements or acoustic measurements, or both, will be required, depending on the nature of the measurand(s).

Turbulent coolant flow will produce acoustic stimulus within the coolant and reactor subassemblies and cause vibration of subassemblies and subassembly components. These stimuli can be detected and measured by microphones coupled to the coolant and accelerometers attached to reactor subassemblies.

(1) Acoustic Measurement

Instrumentation of the NERVA vehicle for ground testing requires the use of acoustic microphones. Analyses of existing transducers indicated that currently available designs could be adapted to the NERVA environment with relatively minor modifications. Hence, no significant development effort was warranted. The required modifications were made and acoustic microphones are now installed in the engine compartment.

(2) Vibration Measurement

The need to make vibration measurements on the NERVA engines posed problems similar to those anticipated for the FFTF requirements, except that temperatures ranged from cryogenic to 500°F. A transducer design for application to 1100°F is presently being considered for use on NERVA high-temperature lines. Because of its experience in making vibration measurements in the NERVA test program, Aerojet has the capability of designing and developing radiation-hardened transducers for application to FFTF.

There is at present no known vibration transducer that can withstand the exposure resulting from permanent installation within the FFTF reactor containment vessel. It is assumed that vibration transducers will be located inside the driver fuel subassembly but above the core and must, therefore, be capable of surviving exposure to the combined environment for the period of one driver fuel subassembly lifetime.

The piezoelectric accelerometer is the most likely candidate as the vibration transducer for application inside the containment vessel of the FFTF. This selection is based on encouraging results with this transducer during development testing of the NERVA engine. With the exception of exposure to molten sodium at 1200°F, the FFTF environmental requirements are quite similar to those of NERVA.

c. Visual Nondestructive Inspection Techniques (NDT)

The extremely high neutron and gamma flux densities which exist during reactor operation, and which will persist even during extensive periods of shutdown, appear to prohibit application of the more conventional visual NDT techniques such as dye penetrant and magnetic particle. However, experience gained by Aerojet during development and production phases of the Polaris missile propulsion systems indicates that both infrared radiometry and eddy-current inspection systems could be developed to nondestructively inspect reactor system components. These techniques would be developed for specific applications to those areas defined during Phase I as requiring surveillance and in-service inspection.

Visual examination and inspection of the basic assembly could also be accomplished by means of radiation-hardened remote-control closed-circuit television camera and display systems. This effort would not be unlike the current use of this equipment to monitor the performance and physics of failure in NERVA engines.

(1) Infrared Nondestructive Testing

Infrared nondestructive testing techniques have been successfully developed at Aerojet for a variety of applications. It is a useful tool to determine discontinuities in metallic and non-metallic structures. Cracks and other types of defects are susceptible to a scanning radiometer method. A control mapping of the reactor wall area would be conducted on initial start-up.

In theory, the radiometer will measure the reactor shell surface temperature: subsurface defects alter the heat flow patterns and thereby affect the surface temperature. An optical system would be devised, using neutron and gamma ray shielding to safeguard the radiometer. A silver reflective surface for the optics and appropriate lead shielding should provide adequate isolation. A control chart would be used initially for comparison to previous run information and, in its ultimate form, data processing could be accomplished with the aid of a computer. Tolerance limits could be set, using other operating data input (e.g., sodium coolant temperature, time from startup, and pumping velocity) to provide more sophisticated judgment. The obvious advantage of this type of inspection would be the ability to continuously evaluate a dynamic condition rather than the conventional static component testing so common in NDT evaluations.

The number of sensors required, their location, and repetition rate of scanning the reactor surface remains a function of Phase II. Reactor drawings and operating details would define locations of the sensors, methods of performing the scans, what shielding would be necessary, and, in general, define the parameters needed to perform the necessary surveillance. Aerojet could design and construct a suitable infrared NDT system to confirm the integrity of the unit.

(2) Polarized Eddy-Current Techniques

The use of infrared detection deserves evaluation primarily because of the commercially available radiometers, scanners and associated equipment. For reasons of convenience of application, Aerojet also proposes to evaluate polarized eddy-current techniques to augment continuous thermographic inspection and surveillance.

The thermal and electrical properties of materials are almost always very similar. By using specially constructed probes, the polarized eddy-current test can show electrical (and therefore thermal)

conductivity in the desired direction. Moreover, such probes could be located on parts of the system from which it would be difficult or impossible to directly measure infrared radiation. The results of polarized eddy-current inspections performed on Polaris components correlated well with actual performance of those components. This is to be expected since the diffusion equation which describes heat transfer in a solid also describes the magnetic field of the eddy-current probe. Therefore, the regions in which the electromagnetic fields penetrate in an anomalous manner may experience severe thermal stresses during sustained application of heat during normal operation. In addition, the simplicity and rugged construction of the probes which could be developed for application to the nuclear system will provide sustained operational reliability in spite of the high neutron and gamma radiation fields.

(3) Other NDT Techniques

There are two other techniques which Aerojet has pursued as far as theoretical feasibility analysis. These include stress-strain measurement using ultrasonics and eddy-sonics. An analysis of stress-strain conditions would provide useful knowledge in anticipating potential failures. Eddy-sonics combine some of the features of eddy-current and acoustic emission by using an electromagnetic field to induce vibrations in metal parts which then may be interpreted in terms of the sonic emissions caused by the vibrations. The applicability of these techniques would, of course, depend upon the results of the work accomplished during the analytical studies of Phase I. However, if such techniques do seem applicable, it is anticipated that successful interpretation of the outputs of these systems would depend to a large extent upon the ability to develop signal analysis correlation circuitry. In this regard, Aerojet is particularly well-qualified by virtue of the experience gained overcoming related problems in designing and fabricating equipment for correlation of microwave inspection return signals.

d. Ultrasonic Inspection for Detection of Crack Formation

The value of ultrasonic inspection under any environmental condition is totally dependent on the techniques used to impinge the ultrasonic signal upon the article to be monitored and the intelligent interpretation of the resulting echo signal. Aerojet's contributions to a project as defined by this proposal is to evaluate the design for the connected type of nondestructive testing (NDT) required by the configuration.

In Phase I of the description of work scope, the NDT specialists' effort would be to recommend, through design analysis, the points within the design disclosure that would be candidate positions for effective monitoring as related to NDT techniques. In coordination with allied specialists in such areas as stress and materials, proposed candidate positions would be evaluated for magnitude as related to suspect physics of failure. Prime candidate positions would then be critically evaluated to determine the best NDT technique to be employed and the parameters of acceptance criteria. Procedures would be developed to obtain ultrasonic mapping graphs of the critical areas for study, after interpretation, by the stress and metallurgical specialists. The purpose of this investigation would be to determine the optimum positions for the pick-ups.

The following are representative of Aerojet's capabilities in ultrasonic work:

Design and fabrication of a solid-state acoustic system to measure liquid height within a separator vessel on a closed loop that generated hydrazine. The acoustic system included four magnetostrictive transducers operating at their self-resonant frequencies.

Production of commercial Acoustic Locating Device (ALD) which is normally used as an underwater beacon. The solid-state amplifiers pulse drive a barium titanate transducer at a frequency of 9 kHz, a repetition rate of 1 second, and a pulse width of 30 milliseconds.

Aerojet has developed and patented a magnetostrictive ferrite ultrasonic transducer for use with a complete range of commercial cleaners and vapor degreasers. This transducer is also used in commercial ultrasonic energy sources to provide high density acoustical energy for instrumentation such as drilling, fluxless soldering, microagitation, growth-rate effects, blood studies, and homogenization.

The commercial line of cleaners and vapor degreasers generally operate at frequencies between 20 kHz and 40 kHz and at modular power increments of 250 watts. Cleaners of 10 kilowatt power levels have been fabricated.

The chief features of the patented transducer are: (1) an 85% electroacoustic efficiency; (2) molded design for bonding to thin metal to produce Chaldni waves for cavitation reinforcement; (3) a "Q" of 6; and (4) a Curie point of 530°C.

A Disclosure of Invention, AGN-190, entitled "Nuclear Reactor Core Diagnostic System", has been filed. This patent application is for a system that uses acoustic energy in a pulsed mode. The disclosure and the developmental work underlying the disclosure are the basis of a current proposal, ANU 67-39, that was submitted to Battelle-Northwest for development of a complete reactor core diagnostic system.

Developmental work was performed at a nominal frequency of 6 kHz, under pulsed and continuous wave modes at input power levels ranging to 30 watts. The transducers were barium titanate and the amplifier drivers were solid state.

A scanning system that employs a focusing transducer for producing a single, narrow ultrasonic beam for locating and discerning objects in sodium has been recently developed. The application of such devices and others previously discussed encompasses the work of Phase II of the study.

e. Other Instruments and Devices

Other instruments and devices must be included when considering diagnostic possibilities. For example, pressure drops and temperature may be needed to indicate flow instabilities and induced vibration. Aerojet's experience in several of these areas is discussed below.

(1) Pressure Transducers

The operation of the FFTF requires diagnostic pressure measurements to be made at various locations both inside and outside of the pressure vessel and associated piping. Pressure transducers being developed for the NERVA and SNAP-8 programs posed development problems similar in nature to those anticipated in the FFTF requirements. Aerojet could develop and provide pressure transducers for the FFTF requirements by combining the existing developed technology and experience of the NERVA and SNAP-8 programs.

The most difficult problem in developing transducers for the FFTF environment is the high operating temperature requirements of up to 1200°F. In nearly all pressure transduction techniques currently available, a conversion is made from a mechanical force proportional to pressure to an electrical signal proportional to the mechanical force. Experience on the NERVA program has shown that at temperatures above 1000°F, nearly all material used in transducer construction experience creep which appears in the transducer output as drift with time. Drift rates of one percent per hour of full scale at 1000°F have been observed in transducers whose electrical parts were capable of operation at considerably higher temperatures.

In the SNAP-8 program, this problem has been overcome by utilizing conventional "off-the-shelf" pressure transducers mounted with short lengths of impulse tubing. Traps are utilized to prevent plugging

of the lines by sodium oxide precipitates. The present state of development offers a readily available method for obtaining diagnostic pressure measurements external to the system.

The measurement of pressures within the pressure vessel sodium pool poses certain development problem. However, pressure internal to the vessel need not be measured in the liquid sodium. Aerojet suggests a relatively simple technique for making all measurements within the reactor pressure vessel.

Aerojet has developed a pressure transducer that will meet all of the environmental requirements existing in the cover gas region above the NERVA reactor. The transducer can be adapted to the LMFBFR measurement requirements by using sensing lines leading to the point of measurement. Since the temperature of the cover gas is expected to be above the precipitating point of sodium oxide, no problem of line clogging is expected.

The NERVA transducer is sufficiently small to permit several to be mounted in a fuel driver assembly. The transducer may also be permanently mounted in the cover gas region for monitoring other internal pressure. The transducer is an all-metal and ceramic unit with a high radiation tolerance. The transducer has been tested to 5.8×10^{17} n/cm² (E > 1.0 Mev) with a 2.75% FS decrease in output. In the cover gas region, the predicted axial neutron flux is 8×10^7 n/cm² sec (E > 0.1 Mev). Since it would take 2×10^3 yr to accumulate the same exposure, this transducer would provide long-life capabilities.

The transducer design is also unique in that thermal, mechanical, and electrical symmetry are incorporated into an integral one-piece body. As a result, no additional circuit balancing or temperature compensating components are required. The transducer is self-temperature compensating over a temperature range of ambient to 600°F, the maximum operating temperature limit.

Although the gamma dose rate in the cover gas region is anticipated to be relatively low, the transducer has been tested to heating rates of 2.76 watts/gm(C)-hr (1×10^9 R/hr).

(2) In-Reactor Coolant Temperature Transducers

Operation of the FFTF and the various test-loop configurations requires radiation-hardened temperature transducers to monitor reactor coolant temperatures. Development of temperature transducers for the NERVA and SNAP-8 programs posed problems similar to those anticipated in the FFTF environment. Combining the design features of the NERVA fast-flux environment transducer with the liquid metal compatibility of the SNAP-8 transducer would provide instruments on a timely basis consistent with the FFTF scheduled needs and avoid a costly duplication of effort in the development program.

The basic problem is the lack of definitive FFTF coolant measurement requirements. However, based on preliminary FFTF design information currently available and anticipating the areas of primary concern for satisfactory reactor operation, reactor safety, and the open- and closed-loop test programs, the minimal measurements are assumed to be:

- (a) Measurement of reactor containment-vessel inlet and outlet coolant temperatures.
- (b) Measurement of reactor-core inlet and outlet coolant temperatures for each driver fuel-test-subassembly.
- (c) Measurement of internal support-structure temperatures.
- (d) Measurement of temperature gradients within the coolant pool.

(3) Electrical Connectors

The operation of the FFTF and its test loops will require the use of remotely operated electrical connectors. Remote engine disconnects currently being designed and developed for use in the NERVA program posed development problems similar in nature to those anticipated in the FFTF requirements. Modification of the present NERVA electrical connector conceptual design for use in the FFTF subassemblies would eliminate a costly parallel development effort and provide connectors on a timely basis consistent with the FFTF scheduled needs.

The basic problem of the FFTF remotely operated electrical connectors is the present lack of tangible design information and requirements. The absence of this information is expected because an electrical connector is an interface component: its design requirements can only be specified after the design of other major components has been finalized. However, the design and development of electrical connectors for the FFTF cannot be delayed. Therefore, certain assumptions regarding the basic requirements of the FFTF electrical connectors must be made in order to initiate this study. The assumptions are discussed below.

The design of the subassembly electrical connector will be governed by the following requirements:

(a) The electrical connector must provide a low-pressure, sodium vapor-tight seal for each subassembly or containment vessel pass-through.

(b) Connector size and pin configuration will be optimized to provide maximum flexibility for the various driver fuel and open- and closed-loop test subassemblies while maintaining standardization for compatibility with the semi-permanent instrumentation monitoring harnesses and the singular mating connector in the fuel handling machine.

(c) The connector will be capable of remote connect and disconnect operation.

(d) The connector will not contain pneumatic lines. Conversion of pneumatic signals to electrical signals will be performed within the containment vessel.

(e) Cables originating within the containment vessel will be metal-sheathed, metallic-oxide-insulated with conductors of copper or thermocouple alloys.

(f) The axial attenuation of the nuclear radiation is sufficient to permit the use of high-radiation-tolerance organic materials at the connector interface elevation.

With a minimum of modification, the current NERVA remote connector design could be made compatible with the FFTF requirements. The present Aerojet design is based on a modular concept. The basis of the concept is the proprietary design of a metal-sheathed cable termination that not only provides hermetic sealing for the cable, but also becomes an individual pin insert in a metal connector matrix. Provisions for hermetic sealing of the connector are included in the design, providing flexibility of pin assignment, ease of cable replacement, and accommodation of conductors of various materials.

The current design, utilizing metal-sheathed cable, permits densities of 38 pins on a 2.5-inch diameter and up to 108 pins in a 4-inch diameter matrix.

With the exception of the sodium-vapor environment, the problem of electrical transmission in the FFTF environment is not different from that presently experienced on the NERVA program. The corrosion or erosion problems associated with sheath cable and their subassemblies can be coordinated with the liquid metal organizations within the Aerojet Nuclear Division.

[(1)(10)e]

D. RELATED CONTRACTS

Specifically related contracts are listed below: first by agency/customer, then by contract number, and finally by title. In addition, a brief description of the activity in most cases follows each listing.

1. Pacific Northwest Laboratory - Battelle

CONTRACT NUMBER: CPFF/Subcontractor

TITLE: FFTF Phase II Alternate Reactor Arrangement-Multiple Vertical Closed Loop Configuration

Conceptual design studies of the split-core FFTF with in-line vertical closed loops. The reactor design studies were integrated with conceptual design studies of the fuel-handling system.

During the development of an overall FFTF design concept, Idaho Nuclear Corporation (INC), an Aerojet-Allied Chemical Corporation subsidiary, contracted to perform studies leading to alternative reactor arrangements. During the study it became evident that to develop an optimum reactor arrangement, concurrent engineering efforts were required relative to fuel-handling system concepts. Consequently, due to Aerojet's extensive remote-handling-systems experience, achieved primarily through the development of large remote systems for the NERVA program, INC requested assistance in this area in June 1966. Aerojet then performed specific reactor configuration and fuel-handling system studies and developed a fuel-handling machine-design concept that would fulfill the fuel element and experiment handling requirements of INC's FFTF reactor concept.

CONTRACT NUMBER: BCA-367

TITLE: Fast Flux Test Facility Fuel Handling System
Conceptual Design Study

Purpose of this study program was to develop one or more feasible fuel-handling-system design concepts that would effectively meet all of the established requirements.

This effort continued original Aerojet work provided in direct support to Idaho Nuclear Corporation studies, but was based on Battelle FFTF design concept requirements.

During the course of this contract, Aerojet has (1) performed the analysis, coordinated customer requirements, and provided research required to establish conceptual design and performance criteria; and (2) performed individual conceptual design studies of overall system types and of required subsystems. These have involved many varied engineering disciplines, including thermodynamics and heat transfer, liquid metals technology and components, instrumentation and controls, nuclear analysis, stress analysis, and remote systems technology.

CONTRACT NUMBER: BSA-418

TITLE: Basic Ordering Agreement

(a) Task Order 1 - Alternate Split Conical Core, Fast Test Reactor - This study effort involves the development of engineering information on the trisected conical core concept and variations thereon in order to develop a geometrical basis for comparative evaluations with other FFTF reactor configurations.

(b) Task Order 2 - Integration Study of Fuel Handling and Radioactive Maintenance Systems-FFTF - This systems integration study involves the development and identification of alternate equipment and system arrangement concepts and operational flow patterns that will effectively and efficiently fulfill the combined functions and requirements of the FFTF System Group 40, Fuel Handling and Radioactive Maintenance.

CONTRACT NUMBER: BCA-367

TITLE: Consultation Services to Develop and Implement a Program Evaluation System for the Fast Flux Test Facility Project

The objective of the work performed under this contract was to provide consulting services to the Customer and assist him in the development and implementation of a program evaluation system for the Fast Flux Test Facility project.

The program evaluation system and associated management information systems developed for and implemented by Battelle-Northwest Laboratories are similar to those that have been in use by the Aerojet-General Corporation - Nuclear Rocket Operations (NRO) for the past four years. The use of such methods and techniques in the management of a complex system is commonplace in NRO (and Aerojet in general). Aerojet has the experience and capability to apply these techniques to the proposed project in a manner entirely consistent with the reporting and format requirements of the program evaluation system in use at Battelle-Northwest on the FFTF Project.

2. United States Atomic Energy Commission

CONTRACT NUMBER: AT(10-1)-880

TITLE: Army Gas-Cooled Reactor Systems Program
(See Background Experience-Next Section AISO)
Nuclear Analysis

ML-1 lid tank experiments, heat generation calculations, and GCRE photoneutron production experiments.

Also conducted steady-state core neutronics, reactor core kinetics and control, lifetime and power distribution changes, reactor shielding, and fission product release studies.

Stress

Thermoelastic analysis of the GCRE-I tube sheet and plenum chamber. Work entails a theoretical thermoelastic analysis of the various structural components involved in the GCRE-I tube sheet and plenum chamber assembly.

CONTRACT NUMBER: AT(04-1)368P.A.1

TITLE: Alkali Metals Program

The object of this program is to determine the transport behavior and thermophysical properties of the alkali metals.

CONTRACT NUMBER: AT(04-3)368 Prog. No. 1

TITLE: Corrosion and Solubility of Structural Material in Liquid Rubidium for Proposed Space Power System

3. The National Aeronautics and Space Administration (NASA)

CONTRACT NUMBER: NAS 9-7759

TITLE: Stress Wave Analysis Technique Monitoring System

Develop system sensitivity for SWAT use on stress corrosion testing.

CONTRACT NUMBER: NAS 7-310

TITLE: Feasibility Study of an Acoustic Depressurization System

Demonstrate feasibility of averting failure of pressure vessel during hydrotest due to undetected flaw growth.

CONTRACT NUMBER: NAS 8-20263

TITLE: Stress-Wave Detection, Saturn S-II

Apply SWAT to Saturn stage test and develop data on aluminum alloy.

CONTRACT NUMBER: NAS 1-4902

TITLE: Characterization of Fatigue-Crack Growth by Stress-Wave Emission

Investigation of fatigue crack propagation in high-strength steels and how this phenomenon is affected by varying strength levels and microstructural and loading conditions.

CONTRACT NUMBER: NAS 9-6766

TITLE: Stress-Wave Test of Apollo SPS Tank

Apply stress-wave analysis technique to titanium fuel tank, exposed to corrosive fluid, during pressurization tests.

CONTRACT NUMBER: NAS 3-2555

TITLE: M-1 Turbopump

The M-1 turbopump is an example of large, complex hardware built by Aerojet. The necessity for building close-tolerance components that must be able to operate at cryogenic temperatures after taking the thermal shock of transition from room to very low temperature, and yet tolerate an adjacent turbine operating at 1000°F, represents a sophisticated piece of hardware that necessitated stringent quality control.

CONTRACT NUMBER: NAS 8-20068, NAS 8-20401

TITLE: "POGO" Analysis of Saturn Propulsion Systems

For these two contracts, the problem of longitudinal (POGO) instabilities due to the coupling of the liquid propellant rocket propulsion system

with the longitudinal vibration mode of the rocket vehicle structure was studied. The study results, applied to the Saturn vehicle, were used to evaluate and design passive feed system compensation devices, and assisted in the analysis of pump pulse test dynamic data. An extensive frequency domain analytical model of the Saturn propulsion system was developed. This model allowed the evaluation of the effect of pressure oscillation suppression devices such as accumulators, resonators, long lines, and gas injection.

CONTRACT NUMBER: NAS 5-417 SNAP 8 (Also see Background Experience - in next section)

Materials

Since the inception and continuation of the SNAP-8 contract 7 years ago, development of component materials has been underway. Work has been performed each year with the objective of providing data to guide the selection of materials and providing metallurgical assistance in the design, development, fabrication, and testing of the system. Some typical reports other than the semi-annual material reports indicate the depth of the experience.

SNAP-8 Mercury Corrosion and Materials Research - 1962

Mercury Corrosion Loop Testing Program - 1963

Accelerated Erosion Testing of Candidate SNAP-8
Turbine Motor and Nozzle Materials - 1964

Mercury Corrosion and Evaluation of Corrosion Product
Separators in 9 Cr-1 Mo. Boiling Thermal Convection Loops - 1964

Other Material Test Analysis:

M-1A Boiler Metallurgical Post-Test Analysis

Failure Analysis of Thermo TI T-104 MRPL2

Metallurgical Failure Analysis of NaK Outlet Tec, TS-1E

Heat Transfer

Tube-In-Tube Boiler Design Analysis

Design analysis of a once-through-type, forced-convection, liquid-metal boiler. The operating heat-transfer and pressure-drop parameters are established as well as the internal geometry of the working fluid flow passage and overall boiler design configuration.

Vibration Instrumentation System

A vibration instrumentation system was designed and installed to monitor the vibration/acceleration of various components in the liquid metal test cells.

Nuclear Analysis

Calculations were performed to predict the system environment and to establish the shielding requirements of the system.

Thermodynamics

Liquid metal heat transfer rates and associated two phase flow dynamics have been the subject of a large number of experimental and theoretical studies.

Computer Codes

The establishment of boiler computer codes for design and performance analysis.

Transients

Determination of the temperature profiles in the entry to the preheater under transient state conditions. Estimates made of temperature distribution during start-up.

Experiments

Forced convection Mercury Boiling-Experimental Investigation. Once-through mercury boiler performance with a helical multipassage plug insert design was studied experimentally. Also studied were concentric counter flow configurations.

Instruments

Liquid Metal Level Measurements. Many concepts developed typical of the types of instrument problems facing the SNAP-8 Program. New adaptation of the concept of using electrical resistance of sheath. Step analog probes, non-linear probes, and non-linear tank levels turned into linear measurements were investigated.

Quality Assurance

Special quality-assurance actions were found to be necessary that were unique to this program. These included the development of very detailed welding procedures for liquid-metal test facility lines, the development of methods of handling and assembling parts in an unusually clean environment, and the application of laboratory techniques to a facility installation and operation.

Reliability

The reliability program was developed reflecting the intent of the NASA. These activities have been integrated with engineering and fabrication efforts. In addition, the plan has been developed to provide a fully coordinated effort with Quality Assurance requirement implementation.

CONTRACT NUMBER: SPUR (SNAP-50) AF 29(601)5131

TITLE: Preliminary Operational Nuclear Safety Analysis for the SPUR System

Studies of metal systems at high temperatures.

CONTRACT NUMBER: NAS 7-367 and 7-544

TITLE: Ultrasonic Inspection

The design of microwave inspection return signal system to identify sonic emissions caused by vibrations.

4. The Space Nuclear Propulsion Office (SNPO); Joint Agency of the Atomic Energy Commission and the NASA (Also see Background Experience in the next section)

CONTRACT NUMBER: SNP-1 (Prime NERVA Contract)

Heat Transfer

Successful test of the NRX-A2 nozzle was the culmination of many months of effort and involved the heat-transfer discipline necessary for the Surveillance Instrumentation Program. Iterative analysis was performed by specialists in the field of heat transfer. Heat-transfer analysis support was also given to the experimental testing of the NRX-A2 assembly.

Materials

Evaluation of corrosion, changes in strength, ductility, and microstructure and crack propagation under stress in liquid metals.

Instrumentation

The analysis, design, development and test of a complete line of instrumentation including accelerometers, pressure transducers, and thermocouples.

NERVA Engine Exhaust System Monitor (FD&S)

Parameters established by Systems Analysis were utilized to establish requirements and design criteria for a system to monitor a large number of critical parameters.

System Data System

A hybrid spectral analyzer with a time-compression, digital-delay, line-storage technique was developed along with digital programs. Other subsystems of a similar complexity were also developed, making the whole of a System Data System.

Nuclear Analysis

The environment of each test is calculated in the course of specifying the tests. Nuclear data are also supplied to component designers, system analyzers, and material evaluators in the development of NERVA components, parts, and systems.

Radiation Effects

The testing of materials and components in a radiation environment for their eventual qualification and use in an operating system.

(Additional Specific and Typical Report Areas)

Instruments

A multi-color infrared radiometer that encodes optical wavelength information from a heated surface as electrical frequency by means of an Aerojet-developed color-coding reticle.

Structural Analysis

Structural Analysis of the XE-1 Pressure Vessel Components and Assembly. Analyses of the ambient-temperature proof hydrotest for the pressure vessel.

Heat Transfer

Steady-state Thermal Analysis of NRX-A6 Pressure Vessel. The purpose of this analysis was to determine full power nuclear steady-state thermal profiles of the pressure vessel under maximum nuclear conditions for use in stress analysis.

Data Analysis

New data analysis techniques have been under analysis for some time. They are primarily concerned with comparing model predictions to actual test data, and interpreting this comparison when both the data and the model are subject to error.

Dynamics

NES/ETS-1 Duct Structural Dynamics

This work consisted of a comprehensive structural dynamic analysis in support of the final structural design concept. Natural frequencies and mode shapes, environmental forcing function simulation, and lumped parameter-dynamic response were used in the analysis.

Malfunction Analysis

Cold-Flow Development Test System Malfunction Analysis

An analysis was made of potential malfunctions relating to testing of the system. Its purpose was to examine areas of possible malfunction, determine the items that might malfunction, and take corrective steps to minimize hazards resulting from the malfunction.

Leak Measurement System

Work produced a performance analysis of the leak measurement system, used during nuclear rocket reactor operation, to indirectly measure the leakage of gases.

Material Test

Limiting-service conditions of AISI Type 347 stainless-steel sheet U-tube materials. Data were obtained to predict material failure.

CONTRACT NUMBER: SNP 35

TITLE: (Phoebus-2 Nozzle Program)

Quality Assurance

Complete quality assurance coverage, starting at the billet, and carrying it through every step of manufacture to a complete, machined product. Because of the size of the unit (the largest billet ever made) and the long time required in production to reach the finished product, errors could not be tolerated. All billets were successfully fabricated into nozzle parts.

Combustion Stability Monitor

A monitor was developed to sense combustion/flow instability and take remedial action during testing operations.

Materials

Severe heat flux and high-temperature technology required new materials technology for the large nickel base alloys.

Heat Transfer

This contract involved research, development and delivery of Phoebus-2 nozzles. This task also involved the type of heat-transfer analysis required for the Surveillance Instrumentation Program, e.g., regenerative heat exchanger cooling, gas side heat-transfer, nuclear heating, and radiative heat transfer.

Nuclear Analysis

Using Monte Carlo analysis of the heat deposition from gamma radiation in the nozzle, Aerojet was able to reduce the uncertainty in the calculated heating rates to the point where a design without external cooling was possible. After reviewing the Aerojet calculations for this program, Los Alamos requested that Aerojet extend its analysis to include the Phoebus-2 pressure vessel as well and provide the results to the manufacturer for his design.

CONTRACT NUMBER: SNPC-4

TITLE: (ETS Facility Design)

Quality Assurance

The E-MAD and ETS-1 facilities employed in the NERVA program required the application of full quality-assurance requirements to complex experimental facilities in which advanced piping flow systems, remote handling equipment, and extensive instrumentation systems were required to operate in nuclear environments.

Nuclear Analysis

In addition to the responsibility for designing the NERVA engine, Aerojet was chosen to design the facility (ETS-1) in which the engine is to be tested and the preliminary planning for a second similar facility (ETS-2). This design activity included more extensive radiation analysis than that associated with the use of the facility for a specific test. The calculations performed include operational and post-run isodose plots, nuclear heat generation, material activation, radiation damage, fission product plateout, facility shielding, and nuclear hazards as related to test stand design, site preparation, and site safety.

5. United States Navy

CONTRACT NUMBER: NOW-62-1007

TITLE: Acoustical Analysis of Filament-Wound Polaris Chambers

Develop method for assessing structural integrity of pressure vessel after manufacturing proof pressure test.

CONTRACT NUMBER: N600(167)-64934(X)(FBM)

TITLE: Feasibility Study for Measuring Fatigue-Crack Growth Rate in Welded HY-80 Steel Using Stress-Wave Emission

Determine the feasibility of using the stress-wave detection system to detect and measure fatigue crack growth rates in HY-80 weld metal and heat-affected zones.

CONTRACT NUMBER: N600(61544)65927

TITLE: Acoustic Emission and Stress Corrosion Cracking in Titanium Alloys

Determine the characteristics of stress-wave emissions in Ti-6AL-4V and other titanium alloys when subjected to a corrosive or stress corrosion environment.

CONTRACT NUMBER: N00014-66-C-0340

TITLE: Investigation of Crack Growth Stress-Wave Relationships

Investigate relationships between stress-wave emission characteristics associated with pop-in under plane-strain conditions and the onset of instability under plane-stress conditions, and how these relationships are effected by material type and condition specimen constraint and stress state.

CONTRACT NUMBER: N0014-67-C-0333

TITLE: Stress-Wave Analysis Technique During Compressive Testing of Glass Hemispheres

Apply stress-wave analysis technique to deep submergence glass hemispheres.

CONTRACT NUMBER: NOW 63-0627

TITLE: R&D in Support of Polaris Program

CONTRACT NUMBER: NOW 61-0491

TITLE: Polaris A3 R&D Support, and A E R&D PLAN

CONTRACT NUMBER: NOW 62-1007

TITLE: Acoustical Analysis of the Strength of Glass Filament Wound Chambers

On these Polaris R&D contracts related work consisted of:

(1) developing and improving thrust-vector control methods for solid rockets and initiating methods of rapid computer analysis of test data; (2) developing methods for the theoretical and experimental stress analysis of rocket nozzles, glass-filament-wound chambers and solid propellants; and (3) conceiving methods for the acoustical analysis of the strength of glass-filament-wound chambers and in the adaptation of displacement gages, microphones, and accelerometers for this purpose.

6. United States Air Force

CONTRACT NUMBER: AF33(615)-5027

TITLE: Acoustic Emission and Prefracture Process in High Strength Metals

Investigate correlations between acoustical emission and prefracture mechanical processes occurring in high-strength steels. Includes effects of noise factors and plastic deformation on acoustic emission.

CONTRACT NUMBER: AF33(615)-2788

TITLE: Investigation of the Mechanism of Slow-Crack-Growth in High-Strength Steels Using a High-Speed Acoustic Detection System

Investigate the effects of varying micro-structural conditions on the mechanisms of slow-crack growth and hydrogen embrittlement in high-strength steel and titanium alloys.

CONTRACT NUMBER: AF33615-67-C-1358

TITLE: Fracture Toughness of Titanium Pressure Vessel Materials

Investigate the fracture toughness of a statistically significant number of forgings and correlate the data obtained with pressure vessel performance.

CONTRACT NUMBER: AF33(600)-36610

TITLE: Wing I and II, Stage II Minuteman R&D

For this Minuteman R&D Program, the activities consisted of thrust vector control and missile dynamics and with the establishment of data formats for telemetering analog and digital data from initial trial flights.

CONTRACT NUMBER: AF04(694)501

TITLE: Minuteman Second Stage

The Minuteman second-stage motor represents an advanced operational solid-fuel motor. It provides a variety of examples that require unusual quality assurance approaches. Since the motor has to meet a 10-year storage life with no degradation in performance, some unusual quality assurance methods were required to demonstrate system adequacy. Every element of this unit is controlled, from raw material through final assembly. The pressure vessel is constructed of very thin drawn titanium and operates at a very low safety factor; therefore, no flaws can be tolerated in the pressure vessel at any stage; the hot-gas lines and valves in the thrust-vector-control system operate at 2200°F and must withstand extensive thermal shock; and the propellant is a very-high-performance type that represents a hazardous operation throughout.

CONTRACT NUMBER: AF04(647)-521

TITLE: Investigation of the Transfer of Oscillations Through the YLR87-AJ-5 Engine System

Theoretical equations of the propellant feed systems of the Titan II ICBM were devised to analyze the transfer of POGO oscillations through the first-stage engine. Special engine tests to verify these equations were made by mechanically inducing oscillations in the pump suction lines. Wide and narrow-band data analysis was performed to provide further refinement of the analytical model. As a result, the resonant frequencies of the feed lines were confirmed to be in the range of the vehicle resonant frequency.

CONTRACT NUMBER: AF33(657)8954

TITLE: Biaxial Creep of Materials in Lithium

An apparatus to measure biaxial creep of alloys in contact with lithium up to 2500°F was constructed and checked out.

CONTRACT NUMBER: AF04(600)-953

TITLE: Aerospace Environmental Chamber Nuclear Analysis

Nuclear design criteria for large aerospace environmental chamber studies.

CONTRACT NUMBER: AF33(616)-8119

TITLE: Tube Burst Test

Evaluation of creep rates in sodium and lithium at high temperatures.

CONTRACT NUMBER: ASD-TDR-67-827

TITLE: Power Generation Techniques

Evaluation of corrosion in thermionic emitters. Tested oxide insulators in contact with liquid alkali metals at high temperature. Analysis of corrosion effects produced during heating by alkali metals.

7. United States Army

CONTRACT NUMBER: DA-44-009-ENG-3641

TITLE: Compatability Study to Facilitate Early Joining of the CORE-GTTF Components

8. United States Department of Defense (DOD)

CONTRACT NUMBER: ARPA - Letter of Intent

TITLE: Research in Nondestructive Testing

Develop new nondestructive test methods.

9. Lawrence Radiation Laboratory

CONTRACT NUMBER: PSA-66-1

TITLE: Acoustic Emission Consultants

Provide consulting services on the use, application, and analysis of acoustic emission techniques.

CONTRACT NUMBER: Subcontract 121

TITLE: On-site Research and Development Assistance Program at UCLRL, Livermore

10. Argonne National Laboratory

CONTRACT NUMBER: 31-1-0-38-2078

TITLE: EBR-II Fuel Elements Fabrication

This program at Aerojet's San Ramon Plant covers production of 34,000 fuel elements for the Experimental Breeder Reactor-II (EBR-II) located at the National Reactor Test Station. The fuel elements are made of uranium alloy fuel pins bonded with sodium in a stainless-steel jacket assembly. The fuel pins are an alloy of 95 w/o uranium (48 w/o U^{238} + 52 w/o U^{235}) plus 5 percent fission elements consisting of molybdenum, ruthenium, rhodium, palladium, zirconium, and niobium.

About 94 pieces of specialized processing equipment are being designed and built to alloy and injection-cast the fuel pins, to machine, weld, assemble the inert components, and to load sodium and fuel pins into a jacket assembly.

11. Commercial

TITLE: SWAT Application to Pipeline

Apply SWAT to pipeline material.

CONTRACT NUMBER: IWA 189,559

TITLE: Idaho Nuclear Corporation

Aerojet-General recently completed the Quality Assurance Policies and Procedures Manual to delineate the policies governing the quality-assurance system at the Idaho Nuclear Corporation, Idaho Falls, Idaho. This manual establishes the quality system and organizational relationships to "provide those systems and functions required to establish compliance with quality systems requirements contained in Atomic Energy Commission and other Governmental publications, and assure conformity of end-use material to quality stipulations contained in applicable design drawings, specifications, and purchase contracts."

CONTRACT NUMBER: Subcontract 365010P

TITLE: Development of Equipment and Techniques for Radiographic Inspection of Full-Scale Propellant Grains

CONTRACT NUMBER: P.O. 400221-OP

TITLE: Design, Fabricate, and Test Portable Interface Bond Detector for Motors

[(1)(10)e]

E. BACKGROUND EXPERIENCE

Background experience is indicated below. These activities deal specifically with liquid-metal technology and nuclear-plant design. A true analysis and criteria evaluation of the surveillance study cannot be appreciated unless this type of background knowledge is part of the firm's past experience, and its personnel's current activities. Aerojet has a strong position in each of these fields.

1. SNAP-8 Power Conversion System

Location: Von Karman Center, Azusa, California

Client: National Aeronautics and Space Administration
Lewis Research Center, Cleveland, Ohio

Contract No.: NAS 5-417

Contract Cost: \$60,000,000

Date of Work: 1960 - Present

Project Description:

In 1960, the Power Systems Division of Aerojet's Von Karman Center was assigned the responsibility for system management and power conversion system design and development for the SNAP-8 system. The reactor portion was assigned to Atomics International.

SNAP-8 is a 35 kw nuclear dynamic power system designed for space applications. There are three major liquid metal loops of the SNAP-8 Power Conversion System. An eutectic sodium-potassium alloy (NaK 78)

is the fluid used in the primary loop to transfer heat from the reactor to the boiler. Mercury is used as the Rankine-cycle working fluid in the second loop. From the boiler, the super-heated mercury vapor is expanded through a four-stage turbine, condensed, and pumped back through the boiler. The heat rejection loop again uses NaK to transport waste heat from the mercury condenser to the radiator from which it is rejected to space. A fourth loop in the SNAP-8 system carries an organic fluid, a mixture of polyphenyl ethers (Mix-4P3E) that cools the pump-motors, the alternator, the space seals, and the electrical controls. It also lubricates the turbine-alternator and mercury pump-motor bearings. The heat from this fluid is rejected through a separate space radiator.

Work Performed:

Based upon customer requirements, Aerojet developed all of the detailed criteria, specifications, and procedures necessary to design, fabricate, and test the SNAP-8 system and its various components. All major components have been fabricated (or purchased to Aerojet specifications) and are presently undergoing development or qualification testing. Five liquid metal test facilities, including the first breadboard system test facility are currently in operation. Corrosion studies have been conducted since the start of the program, and mass transfer studies in boiler materials are presently underway in corrosion loop CL-4. CML is a loop used to investigate the effect of velocity of liquid metals on mass transfer. A 1/7 scale loop is used to investigate short and long time heat transfer effects in the boiler region. Various liquid metal test facilities designed, built, and operated under the SNAP-8 Program are discussed below.

Power Conversion System Loop 1 (PCS-1)

PCS-1 located at Von Karman Center is a three-fluid, four-loop facility designed for component and Rankine-cycle system development testing. This loop is shown in Figure 16, Section IV.

The Primary NaK Loop simulates the reactor coolant loop and is capable of sustained operation at NaK flow rates up to 50,000 lb/hr at 50 psig. Two gas-fired heaters, with combined thermal capacity of 720 kw simulate the reactor and provide the capability to operate up to 1425°F. Provisions are made for manual and automatic flow rate and thermal input control. Thermal transients of 20°F/minute to 600°F and 5°F/minute to 1425°F can be accommodated.

Liquid NaK Loop 3 (LNL-3)

LNL-3 is a single-loop endurance test facility at Von Karman Center, designed for component development testing with NaK. It has flow capability up to 60,000 lb/hr and is rated for 100 psi. The 27 kw electrical heater capacity permits sustained operation at 1320°F.

NaK purity is maintained by cold trapping the oxides and is monitored by plugging meters. Purification is accomplished on-line without interrupting test operations. Steady-state data are recorded on strip charts. Visual gages are utilized for exploratory test operations. The facility incorporates a fail-safe automatic shutdown system that permits unattended operation.

Liquid Mercury Loop 5 (LML-5)

LML-5 is an endurance test facility at Von Karman Center for the development of components utilizing liquid mercury. It tests pump-motor assemblies, valves, and mercury injection systems.

The loop is capable of mercury flow rates of 15,000 lb/hr and 500 psi nominal operating pressure. A 7 kwt electric heater provides the capability for sustained 600°F operation. LML-5 is equipped for exacting tests such as operation at rated flow rates with an NPSH of 0.5 inches of

mercury at 500°F. Space vacuum conditions can be simulated. Data are collected on strip charts and by photographing gages and manometers. The facility is equipped with a fail-safe automatic shutdown system that permits unattended operation.

LML-5 is currently engaged in SNAP-8 component tests.

Mercury Corrosion Loops (CL-1 through CL-4)

The mercury corrosion loops (CL-1 through CL-4) were designed, fabricated, and operated at Aerojet's Nuclear Engineering and Manufacturing Operations facility at San Ramon, California to study the effects of boiling mercury corrosion. The first two loops were constructed with Haynes 25 Material and operated for 1000 and 3000 hours, respectively.

The third loop (CL-3) was constructed entirely of 9CR-1Mo alloy. In this loop, mercury was circulated, boiled, and superheated to 165°F. The mercury was heated in a counter-current heat exchanger by NaK which circulated in the 316 SS primary loop at temperatures up to 1300°F. The mercury was condensed by rejecting heat to another NaK-filled loop constructed of 316 SS. Ultimate heat rejection occurred to air in a fin-tube heat exchanger.

The fourth corrosion loop (CL-4) began operations in 1966 to evaluate mass transfer characteristics of boiler materials, primarily to determine the optimum mercury heat transfer (thermal wetting) conditions. Tests were conducted up to 1200 hours of operation in any single configuration. CL-4 continues to operate after accumulating more than 5500 hours.

Corrosion Mechanism Loop (CML)

SNAP-8 development program included design, fabrication, and test operations of a corrosion mechanism liquid loop (CML) to investigate

the effect of velocity of liquid metals on mass transfer. The corrosion rate velocity dependence of mercury in contact with 9 CR-1Mo steel was determined in April 1967 and the test was terminated.

Seventh Scale Loop

A one-seventh scale SNAP-8 system loop was designed and fabricated to study short and long-term heat transfer effect in the boiler regions. Supporting studies are being conducted in hydrogen migration phenomena and effects, noncondensable gases, liquid metal leakage, and long-term liquid metal instrumentation. The seventh scale loop provides a facility for testing full-scale single-tube boiler test sections. Heat transfer and fluid flow data from these single tube modules are applicable to the SNAP-8 boiler geometry which incorporates seven parallel mercury boiling tubes.

Discussion of Design, Fabrication, and Operational Techniques and Their Surveillance:

The required liquid metal test facilities, including buildings, were designed, constructed, and operated as a part of this program. Specialized procedures and techniques have been worked out in the areas of:

- Design and Fabrication
- Instrumentation
- Data Collection
- Electrical Controls
- Material and Process Specifications
- Quality Assurance and Inspection
- Reliability
- Operational Performance
- Safety

Related special techniques and procedures are discussed below.

Instrumentation

Instrumentation is provided in SNAP-8 for several liquid metal systems. It is used for diagnosis of the performance of the system and components under test, and the control and safety of the entire system. The largest system now in operation, PCS-1 (Power Conversion System 1), incorporates almost 800 measurements.

The basic philosophy employed in the design, selection, procurement, and installation of this instrumentation was that it must first be reliable and secondly be accurate. The system operator must have full confidence in his instrumentation and this confidence is much more grounded on reliability than absolute accuracy. In almost all circumstances, the operator is looking for a trend or a change in measurement indication.

Certain measurements have much greater importance than others since the control of the system and safety of personnel depends upon their reliability. In these cases, redundant instrumentation is often used. Two types of redundancy are utilized: (1) more than one identical or similar instruments are used to make the same measurement; and (2) the same measurement is made by utilizing two completely different instrumentation principles. The two-out-of-three shutdown system utilized presents an example of redundant and identical measurements. To avoid unnecessary shutdowns and to increase reliability, three pressure switches are installed at the same point of pressure measurement. The system will be shut down only if two of the three pressure switches have been actuated.

In some instances, very accurate pressure measurements have to be made over very long periods of time. For these cases, an on-line calibration system is used. The system isolates the pressure transducer from the process line and permits recalibration of the entire instrumentation channel end-to-end (from transducer to recorder) with an inert gas which is removed before the transducer is again allowed to come into contact with the liquid metal process fluid.

Accuracy of electrical transducers (measuring voltage, current, and power) is similarly improved by use of a calibration system which disconnects the loop input to the transducers and applies known calibration signals to the transducers.

The SNAP-8 liquid metal instrumentation system combines the best features of industrial (chemical process control) instrumentation and aerospace instrumentation. Important control functions pertaining to gas-fired heaters are performed with pneumatic recorder-controllers identical to those used in modern chemical plants and refineries. Pneumatic pressure and differential pressure transmitters similar to those used in the process industry are employed as backup (redundant) instruments in the liquid metal loops.

In applications where high accuracy and fast response are of utmost importance, aerospace type instrumentation has been installed. For example, almost 70 absolute and differential pressure transducers using the strain gage principle are installed in PCS-1 system. These can be used up to 600°F, a temperature much higher than industrial transmitter's operational range. This permits installation of the transducer close enough to the process pipe so that the NaK contacting the transducer is kept above the precipitation temperature of Na_2O , thus avoiding any plugging problems. This type transducer also has been modified so that its pressure port cavity permits complete drainage back into the process pipe.

Other features recently developed in the aerospace industry are also used. Signal conditioning equipment and transducers are checked every 24 hours for power supply drift or changes in sensitivity. Vibration measurements are made with the most modern accelerometers, charge amplifiers, and tape recorders. A unique system continuously records important rotating machinery vibration channels and automatically initiates the recording of additional channels upon an unscheduled shutdown. This allows the collection of important vibration data without the expense of continuously operating high capacity channel tape recorders.

Data Collection

SNAP-8 produces a comprehensive data package which includes information on the system and its components. Data stored on magnetic tape in binary coded decimal format is processed on a daily basis to provide a standard data package which includes:

A system schematic diagram for each data point presenting all selected parameters printed on the face of the schematic at appropriate locations.

A complete set of calculated performance parameters such as efficiency, heat balances, etc. for the system and for each major component within the system. These calculations are based on a set of most likely and consistent statepoint values (temperature, pressure, etc.) which are determined by the computer utilizing the instrumentation readings from the system.

System and component performance and historical graphs. These are produced on automatic equipment associated with the computer facility.

Printer plots (made on the digital printer) such as the thermoprofile.

Tabulated raw and processed data in various formats for the previous 24-hour interval.

A tabulation of instrumentation corrections which have been applied to the processed data.

This data can be provided for any designated time interval. The normal time interval selected during steady-state operation is once per hour. The data package which includes approximately 400 parameters is provided to the data users prior to 8:00 AM each day for the data of the preceding day's testing. In this manner, the data is available to the data users at the start of each day.

Provision of data in a form which is readily usable (analysis complete, graphs plotted, format designed for ease of scan, etc.) is highly efficient. The man-machine feedback response time is drastically reduced since deviations and trends are easy to determine.

Methods utilized in the computer codes for the SNAP-8 data processing package are directly applicable to FFTF. These include (1) an instrumentation evaluation analysis code which is utilized to determine instrument shifts and incorporate the appropriate corrections in the processed data, (2) a data processing code which evaluates and averages the data over any specified period of time (user's option) and presents data in tabulated and printer plot format, and (3) a system analysis code which analyzes the system and component performance to determine efficiencies, power distributions, hydraulic losses, heat balances, etc. This information is presented in both schematic and tabulated format and organized so that each data user can easily obtain the information of concern to him. For example, a pump designer can turn directly to a pump performance page and obtain the total picture for the pump.

These codes are compatible with plotting equipment. Graphical presentation of data from them is standard practice in SNAP-8.

FTTF requirements may best lend themselves to a combination of on-line and off-line analysis of the basic reactor system and certain key experiments being conducted within the reactor. Heat balance, component performance, and other pertinent calculated information could be provided on-line

and a complete data package which would require additional computer capacity could be done through an intertie network on-line to a computer facility, or off-line by storing information on magnetic tapes and processing on a daily or other periodic basis.

Material and Process Specifications

Specifications have been developed for all materials that are in contact with liquid metal (304 and 316 SS for NaK service). Basically, ASTM specifications have been upgraded to provide tighter control of such things as chemistry and nonmetallic inclusions and to provide for more quality inspection, both destructive and nondestructive, to guard against internal or surface defects.

Quality Assurance and Inspection

A Quality Program Plan based upon customer requirements, established Corporate policy, and technical objectives of the project, has been developed and implemented. It defines all quality assurance efforts for the program. These are in three general areas: (1) quality planning, which includes participation in design reviews, review and sign-off of drawings, and preparation of inspection plans and tests; prepared for in-house and out-of-house fabrication and for all general procurement; (2) inspection, which includes development of the required inspection techniques where none are available; and (3) collecting, maintaining, and disseminating quality data; includes publishing summary reports which provide management with significant information on quality data, trends, and causes of nonconformance, maintenance of buildup and assembly logs on all major components, and maintenance of inspection records and traceability records.

Reliability

A Reliability Program Plan based on customer requirements was developed. This plan is similar to the proposed FFTF Product Assurance Program.

In addition to performing the conventional reliability functions for SNAP-8, the Reliability Section developed a procedure for determining the reliability of candidate designs for components, systems, and test facilities based upon the methods of bounds. This involves calculation of both upper and lower bounds and a procedure for combining the two to yield a realistically precise estimate of the true reliability value. The refinement includes consideration and utilization of failure modes and their probabilities of occurrence. The method can be used as a substitute for more time-consuming quasi-exact procedures. It involves subtracting probabilities of failure cases from unity to obtain an upper bound and adding probabilities of success cases to obtain a lower bound. The bounds can be brought as close together as desired by considering more and more cases, although the complexity increases geometrically as additional cases are included. However, the method of combining the two bounds make it unnecessary to increase the complexity beyond easily calculated terms.

SNAP-8 also developed an effective "closed-loop" failure reporting analysis, corrective action, and verification test program.

Safety

Proper application of liquid metal safety practices is reflected in the SNAP-8 safety record. During the past year there were no disabling injuries and the minor accident frequency rate was 0.87 per 100,000 man-hours worked.

Aerojet has demonstrated capability in design of safe liquid metal facilities. In addition to the large test loops, it operates two endurance test systems, LNL-5 and LNL-3, 24 hours a day, 7 days a week, unattended. The systems are designed to shut down in event of a malfunction to contain the subsequent reaction with minimal damage to the facility and without hazard to personnel. There have been malfunctions and reactions but the facilities have been reactivated within weeks of these with minimal damage to the facility and no personnel hazards.

2. Nuclear Engine Rocket Vehicle Application (NERVA)

Location: Sacramento, California
and Mercury, Nevada

Client: National Aeronautics and Space Administration
Space Nuclear Propulsion Office
Cleveland, Ohio

Contract No.: SNP-1

Contract Cost: \$160,000,000

Date of Work: 1961 - Continuing

Project Description:

NERVA is to be a 75,000 lb thrust nuclear rocket engine utilizing a 1560 Mw-graphite core, beryllium reflected reactor system for heating liquid hydrogen propellant to 4000°F. The system includes a liquid hydrogen propellant feed system and a thrust chamber assembly with a nozzle, pressure vessel and thrust structure. Auxiliary systems for control and pneumatic power also are included. The NERVA technology development program, scheduled through 1968, has been devoted to research and development tasks utilizing the Los Alamos Scientific Laboratory Kiwi reactor of 100 Mw as a model test assembly. The flight engine program has been conceived in preliminary detail as illustrated in Figure 13.

The NERVA program is divided into several tasks. Included are engine system and component development, ground service equipment development, test facility acquisition, and system test operations at the Nuclear Rocket Development Station (NRDS) near Mercury, Nevada. Several subcontracts and associate contracts have been let by Aerojet and Space Nuclear Propulsion Office (SNPO) to accomplish these task objectives.

Figure 13 - 75,000-lb-Thrust NERVA Flight Engine

Work Performed:

In coordination with customer requirements for NERVA, design criteria documents were prepared by Aerojet for all engine components, ground service equipment, and facility and facility modification requirements. Specifications for material standards, design requirements, fabrication procedures, and inspection also were prepared. Procedure documentation for quality control inspection, proof testing, test operations and maintenance and repair are a standard contractual requirement. In addition, Aerojet has conducted failure mode analyses and nuclear hazard and safety studies in preparing reports necessary to obtain government approval to conduct potentially hazardous reactor and radiation environment test activities.

Selected work performance activities with appropriate system descriptions follow.

Radiation Effects Testing

The NERVA radiation effects program provides assurance, by testing and analyses, that all components and materials will perform their required functions in the environment encountered during engine operation. Fifty-one radiation effects tests have been performed, varying in complexity from static irradiation of components and materials with subsequent post-irradiation testing to dynamic testing and measurement of the performance characteristics of the turbopump bearings and actuators during irradiation. Many unique problems encountered in meeting test requirements were solved by refined engineering techniques with careful attention to materials selection and special shielding arrangements.

One of the most critical problems associated with radiation effects testing is providing radiation resistant diagnostic instrumentation and ancillary circuitry. Otherwise, the performance of test items cannot be assessed accurately. Requirements for NERVA reactor and engine instrumentation systems are even more stringent than those required for the component development programs. Radiation hardened transducers, circuitry, measurement techniques, and installation procedures have been developed and successfully used in the NERVA reactor experiment program. A prime example was the development of a resistance temperature transducer with satisfactory radiation resistance for NERVA application.

Provision of accurate and reliable stimulus to accelerometers, pressure transducers, strain gages, etc., during irradiation testing has broadened Aerojet experience. Maintaining internal temperatures of components and test apparatus within design limits has resulted in the development of analytical programs and techniques that facilitate a rapid and thorough analyses of the effects of gamma heating. As a result of this analytical capability many design features of instrumentation and components have been modified to permit their use in higher gamma heating environments

Radiation Analysis and Shielding

Radiation shielding and hazards analysis were performed and design criteria developed for the nuclear engine test stands in support of NERVA. Shielding calculations established the magnitude of the radiation environment, heat generation rates and temperature distribution for the materials in the test stand areas during reactor operation. Operational and shutdown radiation levels were determined for the test area, control room, and other site areas. Shields were designed so that radiation external to the test stand met with site specifications. Radiation shields also were designed for the test stand to comply with component radiation damage criteria and personnel access criteria after shutdown. Air and ground scattering calculations were

combined with shield penetration calculations to derive isodose plots near the test stand. Problems of access and maintenance during shutdown were defined. Material activation and the resultant gamma dose rates were calculated for both 24 hours and 10 days after shutdown. Reactivity effects of the shields upon NERVA engines also were analyzed.

NERVA Safety

Under contract to SNPO, Aerojet is responsible for overall management and technical direction of the NERVA safety program. It includes both nuclear and non-nuclear (industrial) aspects of safety including such things as radiation protection, criticality control, cryogenics, and fire protection.

The program begins at the earliest phase of facility and system design when conceptual design requirements are reviewed and necessary safety criteria are incorporated. Each progressive design phase is reviewed from a safety standpoint and special precautions and specific safety requirements, as warranted by particular design features, are factored into the overall design effort to establish limits, boundaries and conditions for safe operation.

In designing Engine Test Stand No. 1 (ETS-1) and the Engine Maintenance Assembly and Disassembly Building (E-MAD) for NRDS a detailed review of the facility design and its major systems and components was made to assure compliance with all applicable safety requirements. These complex facilities are used for the assembly, testing, disassembly and postmortem examination of NERVA test articles. Facility radiation shielding requirements, radiation and gas monitoring systems, remote handling systems for radioactive components, radioactive waste disposal and decontamination facilities, as well as conventional safety aspects were thoroughly checked to assure that safety requirements for a total integrated system were incorporated.

The detailed review was continued through the construction phase during which procedures for facility activation and checkout were studied to assure that adequate safety boundaries and conditions were included for each operation. During this phase of the safety review, it became necessary to specify some design modifications to ensure the integrity of the test article during certain test operations. For example, it was found that upon loss of electrical and/or pneumatic signals, certain system valves would fail and jeopardize test operations. This was corrected by changing the failure mode of the valves or by providing redundancy in the system. In another situation, the electrical power distribution had to be modified to assure that no single electrical failure would jeopardize safe shutdown of the test.

The complete safety review of facilities is documented in ETS-1 and E-MAD facility Safety Reports which provide backup information for use during detailed analysis of the test program and operations.

Reliability

The NERVA reliability program provides for developing adequate inherent reliability of the end product. This is done through design review, parts and materials evaluation, failure mode analyses and test plan reviews. Reliability and quality assurance milestones are developed from the program plan management networks for the test articles, component development and major facilities. The events are those of release of design and analysis data packages, specifications, failure mode analyses, test plans and procedures and the conduct of design reviews, reliability evaluations and end item review board type activities. Each major engine and support system component is controlled and followed in this procedure.

Quality Control

NERVA quality control is oriented to product configuration verification and prevention of degradation of the inherent reliability of design. This is done by drawing and specification review for control criteria, the review of integrated inspection planned and its implementation for fabrication, assembly and test, the review of procurement documents and surveillance of inspection and verification efforts, and participation in engineering and end item review boards. The work also includes collection, analysis, storage and retrieval of pertinent data/documentation for reports, reviews and corrective actions. A Test Area Control Plan provides assurance that the inherent reliability of the engine and test support hardware is maintained during the test cycle and furnishes the information necessary to measure and control the quality of the NERVA test program.

3. Nuclear Rocket Engine Test Stand No. 1

Location: Nuclear Rocket Development Station
Jackass Flats, Nevada

Client: Atomic Energy Commission
Albuquerque, New Mexico 1960 - 1962
and
National Aeronautics and Space
Administration - Space Nuclear
Propulsion Office, Cleveland,
Ohio 1962 to
Completion

Contract No: AT(29-2)-1060

Contract Cost: \$2,800,000

Date of Work: 1960 - 1967

Project Description:

Nuclear Rocket Engine Test Stand No. 1 is an experimental reactor/engine test facility used for development testing of the NERVA Rocket Engine. It is illustrated in Figure 14.

Aerojet designed the test facility which consists of a vertical downward firing engine test stand (with provisions for one future vertical stand), a control building, instrumentation and control systems, and complete gas and propellant systems, the nuclear exhaust system and the engine enclosure shielding. Additional facilities include a test cell building and an interconnecting tunnel.

Supporting facilities are a 250,000-gallon spherical storage vessel for liquid hydrogen and 70,000-gallon and 4,400-gallon run tanks.

Figure 14 - Engine Test Stand No. 1; Nuclear Rocket Development
Station, Nevada

Elaborate remote mechanical systems and control of nuclear components are included in the design, as well as cable-ways, terminal facilities, and test stand control and instrumentation systems.

A nuclear exhaust system (NES) provides test stand safety by controlling the disposal of engine exhaust and the venting of fission-product release. The system consists of a duct and a steam generator with their respective piping, valving, instrumentation, and controls. The duct is a welded, stainless steel, double-walled heat exchanger approximately 50 ft high and 50 ft long. A flow of 135 lb/sec of steam is introduced into the secondary portion of the duct to provide an inert atmosphere within the duct in the event of an engine malfunction. The steam generator burns liquid oxygen and propane; the combustion products are cooled by water injection to produce superheated steam. The total duct coolant water flow rate is 34,000 gpm. The heat flux varies from 0.5 to 2.6 BTU/in.² sec. Diagnostic instrumentation is provided to determine or anticipate a system malfunction.

Work Performed:

The work performed by the AETRON Division of Aerojet for the Nuclear Rocket Engine Test Stand No. 1 is covered by several contracts. Initially, under contract to the AEC, Aerojet developed the basic design concepts. Then, under contract to SNPO, Aerojet's AETRON Division developed design criteria and performed preliminary design, final design and a portion of construction inspection for the test stand complex. The design for the NES duct and the engine rest compartment radiation shields were added in the project.

Radiation Analysis

Extensive radiation analyses were conducted to establish design criteria for the test stand, as well as shielding requirements to protect the entire complex. Of prime importance was the evaluation and selection of metal alloy structural materials for minimizing residual activation and nuclear heating.

Radiation analyses were performed out to 10,000 ft from the test stand for evaluation of the shield design for personnel protection. Fine detail analyses were conducted for the region near the engine to determine neutron activation, radiation environmental levels and heating rate effects, thereby establishing the engine enclosure shielding requirements.

Nuclear Exhaust System Duct

Model Test Program. The exhaust duct design was based on the results of a subscale testing program at Aerojet. This testing was completed as a subtask on the NERVA SNP-1 project. This project served to define and verify a selected duct configuration. Heating rates, pressure profiles, Mach numbers and velocities needed for the preliminary design were established.

Preliminary Design. After the basic configuration of the duct had been established by model tests, complete heat transfer, mechanical stress, radiation, materials evaluation and fabrication technique studies were performed and a preliminary design of the duct was completed by Aerojet.

Final Design. Under a separate contract from SNPO, AETRON division of Aerojet performed the final detail design of the duct. This included detail stress analysis, fabrication drawings and specifications with detailed quality assurance provisions.

Engine Test Compartment Radiation Shields

Preliminary design of the test compartment shielding was done concurrently with the radiation environment analyses. After selection of the shielding dimensions, detail distribution of shielding material, the engine system test requirements with respect to fluid and instrumentation and control penetrations and the completion of a eutectic seal test program, the final detail design was done.

4. Alkali Metal Evaluation Program

Location: Aerojet-General Corporation
San Ramon, California

Client: U.S. Atomic Energy Commission
Division of Reactor Development and
Technology

Contract No: AT(04-3)-368

Contract Cost: \$2,100,000

Date of Work: 1960 - Continuing

Project Description:

Aerojet has been carrying on an experimental program at the Nuclear Engineering and Manufacturing Operations facility to evaluate the corrosion, heat transfer, fluid-flow characteristics, and thermophysical properties of sodium, lithium, rubidium, cesium, and potassium for Rankine-cycle technology. This program was recently expanded to cover the study of properties of sodium and lithium, particularly with respect to heat-pipe applications.

The equipment used to perform these evaluations has included dynamic pump loops, furnace-heated capsules, and specially designed equipment to measure thermophysical properties at temperatures up to 2500°F (e.g., vibrating wire for vapor viscosity, laminar flow convective apparatus for vapor thermal conductivity, and null-balance diaphragm capsules for measurement of vapor pressure).

Work Performed:

Corrosion Characteristics

The most significant evaluation of corrosion characteristics has been the operation of two pumped, boiling Cb-1% Zr loops at a boiling temperature of 1850°F, with a subcooled temperature down to 700°F. Rubidium was circulated in the first loop and boiled to a quality of 9%. The loop was run continuously at temperature for 300 hours. Then, a leak developed in a weld; apparently the leak was caused by attack by impurities in the argon atmosphere in the chamber. No significant rubidium corrosion effects were found in the loop. Next, cesium was circulated in the second loop under essentially the same operating conditions used for the rubidium. The cesium loop operated without failure for over 2000 hours at temperature; then, it was shut down for analysis. Both of these loops were operated in an argon atmosphere in AGC's inert atmosphere environmental test chamber.

A capsule study of rubidium corrosion and solubility has also been completed. Boiling reflux capsules were operated to investigate the corrosion characteristics of the following materials over the indicated temperature range:

	<u>Temperature Range, °F</u>
Cb-1% Zr	1400 - 2000
Mo-1/2% Ti	1400 - 2000
Vanadium, commercially pure	1000 - 1200
Haynes-25	1200 - 1800
Be, commercially available (i.e., up to 1% BeO)	1000 - 1600

Heat Transfer

A Cb-1%Zr loop was constructed for use in measuring the boiling heat transfer and fluid flow characteristics of rubidium and cesium. This loop, which utilized some of the components used in the corrosion loops, operated in the same inert-atmosphere chamber. This loop, which had a smooth 3/8-in.-dia. round tube test section, was designed to obtain heat fluxes as great as 325,000 Btu/hr-ft² over the saturation temperature range of 1400 to 1800°F for pressure drops of up to nearly 15% of the saturation pressure.

Thermophysical Properties

- . The latent heat of vaporization of rubidium, cesium, sodium, and potassium was determined in a specially designed apparatus at temperatures from 900 to 2000°F; the standard errors of estimate for these determinations were 0.1%, 0.5%, 0.5%, and 0.8% respectively.
- . The vapor pressure of rubidium, cesium and sodium, and potassium was measured in the apparatus used for the latent heat determination over the same temperature range; the standard errors of estimate for these measurements were 1.1% for rubidium, 0.7% for cesium and potassium, and 1.3% for sodium.

The current program authorizes the determination of the following related thermodynamic and transport properties:

- . Liquid viscosity of rubidium, cesium, lithium, and sodium from the melting point to 2000°F (completed).
- . Specific heat of liquid cesium to 2000°F, and of sodium and lithium to 2200°F (completed).

- . Surface tension and contact angle of lithium and sodium from the melting point to 2500°F for lithium, and to 2200°F for sodium.
- . Liquid thermal conductivity of lithium and sodium.

Purity of Liquid Metals Used During Thermophysical Properties Measurements

Since some thermophysical properties are strongly dependent on the level of impurity concentration, special care was devoted both to obtaining the metals to be tested in their purest form, and to measuring the impurity of the metals before and after testing.

In every case, metals of the highest purity available were ordered from the manufacturers, together with an analysis of the impurity contents. As an additional check, analyses for metallic impurities were also conducted at Aerojet using the emission spectrography method. In addition, before loading in the test apparatus, the liquid metals were hot gettered at 1100 to 1200°F for 6 hours in the presence of zirconium-titanium chips and filtered through 5- and 10-micron stainless-steel filters.

In systems requiring a cover gas, high-purity argon was used. To maintain argon purity to the highest possible level during an experiment, a purification train was provided in which the argon was circulated in a closed loop. This system included a Zr-Ti alloy gettering furnace, a molecular sieve, and an oxygen analyzer.

5. Army Gas-Cooled Reactor System Program (AGCRSP)

Location: San Ramon, California and National Reactor
Test Station, Idaho

Client: Army - AEC
U. S. Army Corps of Engineers
USAEC Army Reactors Organization

Contract No.: DA-44-192-ENG8
AT(10-1)-880

Contract Cost: \$49,485,000

Date of Work: 1956 - 1967

Project Description:

AGCRSP was a program to develop a 300-kw mobile nuclear power plant for trailer-mounted operation by military personnel at remote installations. The system combines a gas-cooled reactor and a closed-cycle gas turbine.

The program was conducted under AEC Contract AT(10-1)-880. Technical cognizance was vested in Aerojet-General Nucleonics, a subsidiary (now a division) of Aerojet-General Corporation.

Work began in the fall of 1956 with the design of a reactor-fuel test system, the Gas-Cooled Reactor Experiment (GCRE). Performance specifications for the field power plant were finalized by DOD in mid-1959 and design, development and fabrication of a prototype plant was then initiated. The reactor skid, power conversion skid, and control cab were delivered to the National Reactor Testing Station (NRTS) for testing in the spring of 1961. Testing of the Mobile, Low-Power, first prototype (ML-1) power plant at the NRTS proceeded from September 1962 until August 1965.

By October 1965, many of the technical and program objectives of AGCRSP were achieved. The Army has continued to fund the development of the power conversion system under the Army Power Conversion Skid Experiment (APCSE) to demonstrate a 300-kw packaged, mobile power conversion skid. The ML-1 is shown in Figure 15.

Work Performed:

Aerojet-functioned as the full systems manager for the AGCRSP. A demonstration reactor GCRE was first designed, fabricated and installed at NRTS. The GCRE reactor facility criteria was developed by Aerojet for design by Aerojet-General's AETRON Division. AETRON was also responsible for construction management of the facility.

The GCRE went critical in 1960 and was operated to demonstrate the ML-1 reactor design feasibility and to train Army and Aerojet operating crews. The reactor operated at 2.3 Mw thermal with an 800°F gas inlet temperature and a 1200°F outlet temperature.

Aerojet subsequently designed, developed and manufactured the reactor portion of the ML-1 system, fuel elements, control system, fission product detection apparatus and a complete waste handling system for field application. Also, the Company was responsible for design specifications and surveillance on component and subassembly contracts issued by either themselves or the Army Corps of Engineers related to the power conversion hardware. All the power conversion components were assembled by Aerojet in the power conversion skid. Aerojet was responsible for the integration and interface control with all major equipment suppliers and with the Army Corps of Engineers and the AEC.

The three modules of the ML-1 system, reactor, power conversion equipment and Control Cab were skid-mounted, mated and operated at NRTS as an operational proof test of the systems ability to produce 300 Kwe. Aerojet

Figure 15 - Gas-Cooled Reactor Experiment Showing Reactor Located
in a 30-ft-Deep Pool of Water at NRTS, Idaho

prepared the necessary design hazards reports and presented the system before the ACRS.

In the course of the program, documented operating procedures and maintenance manuals for ML-1 were prepared to provide an integrated instruction package for Army operating personnel.

Safety

All operations at the GCRE and ML-1 were controlled by detailed procedures prepared prior to the initiation of any specific phase of the activity. Such procedures covered the experimental program as well as the "normal" operation of the reactor, the operation of all support equipment in the facility, the maintenance of the reactor and facility equipment and all administrative tasks. The fundamental goal of the procedure system was to ensure, through comprehensive and methodical planning, that no unanticipated event would occur. Strict compliance with the procedures at all levels of the organization was specified as a condition of continued employment.

The next phase of the planning involved the preparation of detailed procedures covering all aspects of the operation, maintenance and administration at the GCRE facility. Each procedure covered rod system, startup of the main compressor, reactor startup, normal reactor shutdown, emergency reactor shutdown, dry critical experiment, etc., and were so comprehensive and detailed that the necessity for independent judgment on the part of the operator was essentially eliminated in all routine and emergency situations. A basic rule in the preparation of a procedure was that no condition be specified which resulted in violation of the limits presented in the appropriate Technical Standard.

Prior to final approval and issuance for general usage, all Technical Standards and all critical procedures (those related to reactor operation or involving considerations of nuclear safety) were carefully reviewed and approved by a Procedure Review Board (PRB). The membership of this board included the most experienced and knowledgeable persons at Aerojet.

6. Aerojet-General Nuclear Industrial Reactor (AGNIR)

Location: San Ramon, California

Client: Aerojet-General Corporation

Contract No.: Company Sponsored

Contract Cost: -

Date of Work: 1964 - 1965

Project Description:

To support its variety of Nuclear Programs, and to provide services to other industrial and government organizations, Aerojet has built an industrial irradiation facility that includes a 250-kw reactor, a very versatile hot cell and a radio chemistry laboratory, all in the same building.

Work Performed:

The irradiation facility with cooling system, control system, ventilation system and enclosure safety system was designed and the fabrication and construction controlled by Aerojet. Nucleonics, heat transfer, shielding, and hazards analyses were performed to assure a successful irradiation facility. Siting and hazards analyses included considerations for reactor dynamics, topography, hydrology, geology, climatology, and seismology.

The facility is being operated and maintained by Aerojet to perform a variety of industrial irradiation programs with the attendant considerations of safety, shielding and waste disposal.

Safety

Since the AGNIR falls under the jurisdiction of the AEC Division of Reactor Licensing, the extensive procedures outlined in Title 10, Code of Federal Regulations were followed in licensing the facility. Included in these procedures is the application for a construction permit for a production and utilization facility under which the AGNIR is categorized. This application must include the technical information hazards summary report. Such a report entitled Aerojet-General Nucleonics Industrial Reactor (AGNIR) Hazards Summary Report AN-1193, September 1964, was prepared.

Once the construction permit had been granted, the facility construction was begun. Prior to completion of construction Technical Specifications were prepared and an operating license application was prepared. At the completion of construction but prior to initial criticality the AEC inspected the facility, qualified several reactor operators and verified that the facility complied with the submitted Technical Specifications. Upon receipt and approval of the inspector's report, an operating license was issued. The initial criticality of the AGNIR was then performed under the surveillance of an AEC inspector.

Subsequently, safety is supervised by the Reactor Supervisor, and the Radiological Safety Officer, the Radiological Safety Committee and the Reactor Safety Committee, all of which report to the Plant Manager, San Ramon Operations.

Individual experiments are evaluated prior to insertion into the reactor by the above personnel and committees. Experiments are evaluated to determine whether they can be performed under the existing Technical Specifications, or whether the experiment falls outside the Technical Specifications and a Technical Specification Change is required to perform a given experiment. If a change is required a hazard report covering the change

must be submitted to the AEC Division of Licensing for approval, without which the experiment cannot be performed.

Quality Control

Quality control is very important on all items that affect the safety of the AGNIR. Experiments that are inserted into the AGNIR case must pass very stringent inspections which include pressure testing of pressure vessels, dye-penetrant and X-ray inspection of welds, dimensional checks and material composition certifications of varying complexity and testing verification. All components that are placed in the reactor pool must be compatible with the other reactor components from a corrosion standpoint and tight quality control is exercised on all in-pool reactor components.

7. AGN 201 and 211 Commercial Training Reactors

Location: San Ramon, California

Client: Twenty-one purchasers

Contract No.: Developed by Aerojet

Contract Cost: \$95,000 to \$150,000 each

Date of Work: 1956 - 1959

Project Description:

Aerojet developed and produced as a strictly commercial venture two classes of training reactors called the AGN 201 and AGN 211, respectively.

The 100 Mw AGC 201 Reactor was the first quantity-produced reactor in the world. It was designed specifically for training nuclear engineering graduate students and producing short lived radioisotopes. Design criteria included complete inherent safety, simplicity, minimum critical mass, small over-all size, and ease of installation. Safety is afforded by the reactor's large negative temperature coefficient which would immediately terminate an excursion by loss of reactivity. Recurrence of the excursion is prevented by the melting of a fuse link that supports the lower half at the center of the core, thus separating the upper and lower halves of the core. The polystyrene fuse has a lower melting point and a higher loading of U-235 than the balance of the core so that its temperature will be higher than that of the core.

The reactor was a polyethylene-UO₂ cylindrical core about 10 inches in diameter by 10 inches in height. The core, with eight-inch-thick

graphite end reflectors above and below, is contained in a sealed aluminum core tank. The core tank is surrounded by a 4-inch-thick graphite reflector and a 4 inch ring of lead. Final shielding is provided by 18 inches of water in a tank surrounding the core's assembly.

Control rods are made of the same material as the core. Withdrawal of the rods results in a 6 to 8 percent shutdown margin. Since they are fuel loaded, reactivity is decreased more rapidly from the full in position than would be achieved by insertion of poison-type control rods from the full out position.

Although initially designed for 100 Mw operation, several of the later models of the AGN 201 were adapted for operation at higher levels. Modifications included the addition of more excess reactivity (to compensate for the somewhat higher core equilibrium temperature) and external concrete block shielding.

AGN 201 reactors were displayed and operated under USAEC contracts at the 1958 Geneva Atoms for Peace Exposition and at the 1958 Rome Nuclear Congress.

The 100 AGN 211 Reactor incorporates the inherently safe fuel of the AGN 201 into a pool type design for more flexible educational and isotope production. It allows direct access to the fuel elements so that core parameters can be varied and the effects studied. The core is composed of 10 fuel elements each 10 inches high with a 3 by 3 inch square cross section. The core is reflected top and bottom with 5 inches of graphite and on the sides with 3 to 6 inches of graphite. Water is used for gamma and neutron shielding in all directions. In addition, a 40-inch-thick concrete shield surrounds all sides of the reactor tank. A 2-inch lead shadow shield is used at the top of the graphite reflector to reduce the tank height to 8 feet.

Inherent safety of the Aerojet reactors was the basis for the selection of an AGN 211 pool type by the United States AEC for display at the International Science Pavilion of the Brussels World's Exposition. The one displayed was the first one built, with the design and construction being dismantled, shipped to Brussels, and placed in operation for the opening of the World's Fair all within four and one-half months.

Work Performed:

Methods of Manufacture

Production of AGN 201 and 211 reactors in quantity required interchangeability of parts, assembly line operation, and other multiple production techniques. For example, 90 percent of the control rod parts and the console were interchangeable on both reactors. Design and fabrication were complicated by the requirement for easy assembly and disassembly and an overall package size to permit shipment. All AGN reactors have been assembled, taken critical, and fully tested at the San Ramon Plant prior to disassembly and shipment to the customer.

Production Volume

Seventeen AGN 201 reactors have been built and are now in operation throughout the United States and Europe. Two were modified prior to delivery for operation up to 5 watts. Three others were subsequently modified for intermittent operation at power levels up to 1000 watts. Three were delivered to Government agencies and all others went to universities.

Four AGN 211 reactors now in continuous operation are operating at power levels from 15 to 1000 watts.

All AGN 201 and 211 reactors produced by the Company are in operation today. All are 8 to 11 years old; one-third are in the hands of a second owner, attesting to their reliability.

Control Console

The control console unit is used for both reactors. It comprises measuring and recording devices for radiation at the various levels experienced during operation, control instrumentation for positioning control rods, a graphic display indicating rod position, and automatic circuits that monitor radiation and detectors for other hazards, (such as earthquake). The automatic circuits affect immediate shutdown when predetermined levels are exceeded. Chassis are assembled and tested before installation in the console frame and final connection. Consoles are tested with bench-mounted control mechanisms and radioactive sources that simulate the radiation in the ionization chambers. Final acceptance requires repetitive cycling of all systems before assembly of the reactor.

SECTION IV - MANAGEMENT

Table of Contents

	<u>Page</u>
(6)* A. STUDY ORGANIZATION	IV-1
1. Responsibilities and Authority	IV-2
a. Project Management in Both Phases	IV-2
b. Project Engineering Phase I	IV-4
c. Project Engineering Phase II	IV-6
(5) (8) 2. Project and Backup Personnel	IV-8
a. Project Personnel Resumes	IV-10
b. Backup Personnel Resumes	IV-60
(7) e 3. Project Plan	IV-102
a. Discussion of Work Scope	IV-102
b. Discussion of Schedule	IV-108
(7) e B. PLAN, SCHEDULE AND CONTROL	IV-110
1. General Concept	IV-110
2. Management Information System Components	IV-112
a. Standardized Reporting System	IV-113
b. Independent Program Evaluation	IV-114
c. Management Center	IV-114
d. Weekly Management Review in Management Center	IV-115
e. Special Management Tools	IV-115
C. ESTIMATED COSTS AND OTHER FACTORS	IV-117
1. Estimated Costs	IV-117
a. Cost Element Discussion	IV-117
b. Other Contract Factors	IV-118
(2) e 2. Project Location	IV-119
(3) 3. Workload	IV-119

*Indicates question number of RM-5-RFP Questionnaire-Instruction List which is answered in Section IV.

Aerojet-General Corporation's SNAP 8
(PCS-1) Test Facility

Figure 16 - SNAP-8 (PCS-1)

As part of the SNAP-8 program, Aerojet has designed and fabricated all of the liquid-metal test-loop components that are now under test in the system pictured above. The reactor is replaced by gas-fired heaters in this loop. Aerojet has two other liquid-metal loops in Azusa, California, and several research loops in San Ramon, California. Instrumentation to survey and monitor and a surveillance system are part of these loops.

Table of Contents (cont.)

		<u>Page</u>
(2) e (4)	4. Design and Engineering Facilities	IV-121
	a. Engineering R&D Laboratories	IV-122
	b. Computing Facilities	IV-125
	c. Technical Library	IV-128
	d. Technical Document Center	IV-130
(9)	5. Outside Assistance	IV-130

IV. MANAGEMENT

This proposal has identified Aerojet's capability to participate in the development of the FFTF Surveillance Monitoring System. Discussions in 1967 with FFTF Project personnel on the particular problems involved with surveillance and Aerojet's proposal (NPS681105) for a feasibility study of such a system to the FFTF Development Division in January 1968 should indicate this firm's sincere desire and willingness to participate.

The project organization that can be made available immediately for this work is well versed in all technologies of a Surveillance Monitoring System for Liquid Metal Fast Breeder Reactor Plants. The project group is extremely interested in this program and believes that it will provide a substantial degree of assistance to the FFTF Program objectives.

This Management Section (IV) includes discussion of the study organization, plans, schedules, and controls; and estimated costs and other factors. This section answers all questions asked in the RFP-RM5 Questionnaire-Instruction List with the exception of numbers 1 and 10. Answers to questions 2 through 9 are keyed in the margin of this section. Answers to questions 1 and 10 are to be found throughout Section III, Experience.

A. STUDY ORGANIZATION

Based on the experience and requirements discussed in Section III, Experience, of this proposal and the description of efforts in Phases I and II of this study as described in RFP RM-5, the project organization is structured as illustrated in Figures 17, 18, and 19.

[(6)]

1. Responsibilities and Authority

Responsibilities and authority depend on the level of project management and/or engineering and phase in which specific requirements exist.

a. Project Management in Both Phases

Project Management in both phases is illustrated in Figure 17. The Nuclear Division of Aerojet-General Corporation is charged with the responsibility of conducting the Surveillance Study effort. Under Dr. C. C. Ross and his Operations Manager, Dr. W. O. Wetmore, the management of this activity is carried out much as the other FFTF-related projects such as the Fuel Handling System Alternate Split Conical Core and System Group 40 studies have been and are being administered now. Mr. J. J. Beereboom is directly responsible for the overall management of the work. As such, he will be guided by the Plan, Schedule, and Control System mutually established by him and the Independent Program Review Group. This system is described in Section IV.B. Mr. Beereboom's department is made up of the Engine and Control System Sections, and the Systems Analysis, Nuclear Analysis, and Facility Engineering Sections among others.

The Study Project Engineer, Mr. E. E. Duke, is immediately involved in the planning, scheduling, and immediate control of the project. Mr. Duke will be assisted on a technical basis by his Staff Consultants. This group contains experts at a Staff level in the areas of FFTF Liaison, Instrumentation, Systems, and Support that will review and recommend to the Project Engineer. They are available for direct assistance and/or consultation with the Project Group involved in the study. The Study Project Engineer and his assistants, the Project Engineer for Analysis and the Project Engineer for Support, form the basis of a technical review committee which coordinates and directs the technical work. The Analysis Project Engineer is responsible for all technical analysis and the coordination between

Figure 17 - Project Management, Both Phases

analysis groups. The Support Project Engineer is responsible for all support activities. The Study Project Engineer is responsible for coordinating the activities of his two Project Engineers and ensuring the communication between the two. The Study Engineer, along with the two Project Engineers also have direct authority to make technical and programmatic presentations to Battelle and formulate future plans for the work in close liaison with Battelle's requirements.

b. Project Engineering Phase I

The Project Engineers shown in Figure 18 have the responsibility of coordinating their efforts and together with the Study Engineer, have the authority of technical direction and management of the project.

(1) Project Engineer - Analysis

The Project Engineer of Analysis has direct responsibility of directing the technical groups under his jurisdiction and the authority to see that good technical coordination between personnel takes place. In order to ensure this coordination, technical review and discussion meetings will be held as frequently as necessary.

In addition, at the direction of the Study Engineer, the Project Engineers and the participating personnel under their jurisdiction will be called together as necessary to discuss technical problems of a coordinating nature.

The Project Engineer will have the responsibility and authority to describe the work scope of each of his personnel's activity and issue work authorizations with the concurrence of the Study Engineer.

Figure 18 - Project Engineering, Phase I

The budgets and work scope thus established with the assistance of the various personnel and concurrence of the Study Engineer will be managed by the Project Engineer. He will report to the Study Engineer at least on a weekly basis the technical progress and budgetary scheduling status.

In order not to impede progress, all group engineers (whether analysis or support) have authority to coordinate among themselves, and in fact have the responsibility to do so as required, in performing the work scope to the best of their ability. Coordination details established need only be discussed in the weekly project meetings. At no time will any arrangement be established to impede progress. The arrangements described merely ensures proper, adequate, and accurate coordination.

(2) Project Engineer Support

The Project Engineer Support has similar and parallel responsibilities and authority as does the Project Engineer - Analysis. However, as a support organization, he has the additional responsibility of ensuring that his support capabilities are continually made known and utilized by the analysis groups. In order for the Support Project Engineer to be active to the fullest he is also responsible as a group engineer for cost evaluation. This appointment simplifies the conductance of the task because it allows the Support Project Engineer to freely gain access to cost information from the Analysis Group since he is continually coordinating with the Project Engineer - Analysis.

c. Project Engineering, Phase II

The Project Engineers for Phase II have the same responsibilities and authority as the Project Engineers in Phase I. The project plan in Section IV,A,3, indicates that the two portions of Phase II, namely literature search and conceptual design of the NDT system can be a

Figure 19 - Project Engineering, Phase II

parallel effort for at least 4 months of the 6 month literature search effort. In this way, results will be established earlier and in a time period when development of the system could begin. Because of this parallel effort, the two Project Engineering Groups must cooperate and coordinate just as the Project Engineering Group did during Phase I.

"Technical Analysis as Needed" shown on Figure 19 indicates that the respective Project Engineers can call on expert technical analysis as the study progresses. For example, the literature search may indicate that no transducer is available for a particular requirement. Development efforts are then suggested, but only on those types of transducers which show promise. That they show promise might come about only after material, nuclear, and thermoanalysis of a large group of candidate type designed transducers have been evaluated. The Project Engineers at the request of their personnel have the responsibility to see that this technical work is carried out and the authority to establish a work scope in conjunction with the technical group.

[(5)(8)] 2. Project and Backup Personnel

Based on the technical and project requirements discussed in the previous section, Aerojet presents for study consideration the following Project Personnel and Backup Personnel consisting of those readily available and most experienced in the respective areas.

Program and Staff Personnel

<u>Position</u>	<u>Program Personnel</u>
Program Manager	J. J. Beereboom
<u>Staff</u>	
Independent Prog. Rev.	G. N. Eisenhart
FFTF Liaison	S. Harbison

<u>Staff (cont.)</u>	<u>Program Personnel</u>
Instrumentation	W. P. Gilles
Systems	D. Buden
Support	C. F. Leyse

<u>Study Project Personnel</u>		
<u>Position</u>	<u>Project Personnel</u>	<u>Backup Personnel</u>
Study Project Manager	Edward E. Duke	Leslie L. White
<u>Phase I (Project)</u>		
Project Engineer-Analysis	Arnold J. Bermingham	Allan H. Flagg
Project Engineer-Support	Leslie A. Welge	Steven S. Bacharach
<u>Phase II (Project)</u>		
Project Engineer - Systems Analysis	J. H. Altseimer	David L. Limbacher
Project Engineer - Literature Support	Stanley K. Yoder	Ernest R. Sita
<u>Phase I (Group)</u>		
Group Engineer - Nuclear Analysis	Dr. Jack A. Vreeland	A. D. Wilcox
Group Engineer - Thermodynamic Analysis	Dr. K. Sato	Allan H. Kreeger, Hal J. Snyder, Susumu Nakazato
Group Engineer - Material Evaluation	Dr. C. E. Dixon	Irwin M. Rehn, G. W. Titus, Carl E. Hartbower
Group Engineer - Radiation Effects	David E. Deutsch	William Kountanis
Group Engineer - Stress, Strain & Vibration	Dr. T. O'Callaghan	L. L. Bickford, R. C. Rosser
Group Engineer - Reliability & Q.C.	J. S. Goddard	L. G. Schrieger
Group Engineer - Safety Analysis	Stanley H. Klein	Donald S. Duncan
Group Engineer - Costs	Leslie A. Welge	Steven S. Bacharach

<u>Position</u>	<u>Project Personnel</u>	<u>Backup Personnel</u>
<u>Phase II (Group)</u>		
Group Engineer - System Applicability	Allen T. Green	R. K. Steele
Group Engineer - Instrumentation	Louis G. DelValle	Rodney Hoff, Donald E. Swartz
Group Engineer - System Acquisition	H. Benenson	S. Dairiki
Group Engineer - Development	Allen T. Green	Stephen A. Mainstrom
Group Engineer - Inspection Methods	L. G. Schwieger	J. S. Goddard, Donald G. Kneeland
Group Engineer - Instr. Candidates	Robert Siev	Ernest R. Sita
Group Engineers - Technical Analysis - As Needed, from Phase I Group Engineers		

Resumes for project and for backup personnel follow:

a. Project Personnel Resumes

(Resumes are placed in descending project organizational order).

J. J. BEEREBOOM - Program Manager

Education

B.S.Che.E., University of Detroit, 1942
Graduate Study, U C.L.A., 1957 - 1960

Experience

1955 - Present: Aerojet-General Corporation. In his present assignment as Manager of the Systems Department, Nuclear Rocket Operations of the Nuclear Division, Mr. Beereboom is responsible for meeting the contractual milestones and directing the technical and administrative activities of the department.

Prior to his present assignment, Mr. Beereboom was Manager of the Phoebus-2 Nozzle Development Program.

Previous to this, Mr. Beereboom was Assistant Manager, Component Development Division, REON. In this capacity he assisted the Division Manager in directing the design and development of the NERVA components, including the thrust chamber assembly which includes the NERVA nozzle.

Mr. Beereboom joined the Special Projects Department, REON, in 1961, as Program Manager in charge of the Kiwi-B Nozzle program. In his position as Program Manager, he was responsible for organizing and directing Aerojet's activity in the design and development of rocket exhaust nozzles for the Kiwi-B reactor experiments. At the conclusion of the Kiwi nozzle development, Mr. Beereboom became Assistant Manager of the Engine Department, REON. As Assistant Manager, he was responsible for directing the design activities and component integration of the NERVA engine under Task 1.1.

In his last assignment before joining REON, Mr. Beereboom was Program Manager and Department Head, Vehicles Department. In this capacity he was responsible for the Aerobee 150A, Astrobee 200 and 500 Sounding Rockets, the Aerojet Recovery System, the Micrometeorite Payloads, and the Firefly Payloads contracts. As Program Manager and Department Head he was responsible for the administration, program planning, budgets, and technical and fiscal monitoring of assigned contracts.

Mr. Beereboom joined Aerojet in 1955 as a member of the Thrust Chamber Staff Group. His duties consisted of producing detailed designs, including the heat-transfer analysis for the Vanguard (now Able and Delta) thrust chamber. As a member of the Thrust Chamber Staff Group, he also participated in the design and development of the Aerobee, XLR-73, Bomarc, and Advanced Bomarc rocket engines.

Affiliations

Member of the American Institute of Aeronautics and Astronautics

GEORGE NORMAN EISENHART - Staff Consultant - Independent Program Review

Education

B.S. in Aeronautical Engineering, Georgia Institute of Technology, 1937.
Master of Business Administration, Stanford University, 1957.
Master Majors: Management and Executive Control, Applied Business
Physiology

Experience

1963 - Present: Aerojet-General Corporation, Mr. Eisenhart's present assignment is Program Evaluator for Nuclear Division. Previously, Mr. Eisenhart was Manager, Program Evaluation Department, Nuclear Rocket Operations. In that capacity, he developed a management review technique and information presentation system, made independent evaluations of NRO programs for top management decision-making, and assisted in establishing program evaluation at Battelle Northwest for the Fast Flux Test Facility.

1962 - 1963: Director of Program Policy and Review, Bureau of Naval Weapons. In this capacity, Mr. Eisenhart was responsible for the evaluation for the Navy's major weapons systems, and developed many management techniques and policies. He directed PERT operations at the Bureau, and served on the Department of Defense/National Aeronautics and Space Administration PERT Coordinating Group.

1939 - 1962: Various assignments with the United States Naval Air Corps. This included International Program Manager and Contracting Officer in Japan, producing ASW aircraft in, by, and for Japan (1959-1962); Electronics Equipment Inspection and Acceptance Officer, Bendix Corporation, Teterboro, New Jersey (1957-1959); Chief Test Pilot, Johnsville, Pennsylvania, and Alameda, California, facilities (1946-1959); and Patrol Plane Commander and Task Force Air Group Commander (1939-1946).

Publications

"REON Program Management System, A Proposal for" - March 1964

"BuWeps Program Manager's Manual" - June 1963

"PROMPT, A Management System for Multi-Program Control" -
April 1963

S. G. HARBISON, Staff Consultant - FFTF Liaison

Education

B.S., Mechanical Engineering, Mississippi State College, 1952
U.S.A.F. Airborne Electronics School, 1953

Experience

May 1962 - Present: Aerojet-General Corporation. Section Manager, FFTF/LMFBR Programs and HTGR Equipment Servicing System Program. Mr. Harbison is responsible for overall management, administration, organization, coordination, and direction of the Alternate Split Conical Study (FFTF) for Battelle-Northwest, Integration Study of Fuel Handling and Radioactive Maintenance Systems (FFTF) for Battelle-Northwest, and HTGR Equipment Servicing System for Gulf General Atomics programs and for the fulfillment of technical and programmatic objectives within schedule and budget limitations. Also responsible for coordination of proposals related to LMFBR and HTGR projects.

Previously, as supervisor of the Special Projects Group of the Support Systems Section of NRO, his duties and responsibilities included the organization, coordination, and direction of efforts related to special remote handling system engineering studies, preparation of proposals and brochures, and investigation of new areas of remote handling system applications. Served as Program Manager of contract with Battelle-Northwest to develop conceptual designs of a Fuel Handling System for the Fast Flux Test Facility and as Chief Project Engineer of a program to design, develop, and test an underwater version of a special space Bolt Removal Tool for Marshall Space Flight Center. Mr. Harbison also served as Project Manager of a conceptual design study of Fuel Handling Systems in support of Idaho Nuclear Corporation's FFTF Concept Study Program.

In the capacity of Project Engineer in the Support Systems Section, he was responsible for the Overhead Positioning System, Floor Mounted Handling System, Postoperative Cell Material Transfer System, and other remotely operable equipment required for the NERVA disassembly and postoperative examination in the E-MAD Building at the Nuclear Rocket Development Station, Jackass Flats, Nevada. He also coordinated subcontractor's fabrication efforts and installation and checkout activities at the test site, prepared specifications and test procedures, monitored costs, approved design changes, and provided technical direction.

Oct. 1957 - May 1962: Thiokol Chemical Corp., Marshall, Texas. As a Senior Engineer in the Engineering Department, he was responsible for the design, development and application of production and inspection equipment and tooling for various solid rocket motor production programs.

Jan. 1956 - Oct. 1957: Austin Company, Cleveland, Ohio. Assigned as Design Engineer, he was responsible for design and analysis of air conditioning, heating, refrigeration and ventilation systems for industrial and commercial facilities.

Aug. 1954 - Jan. 1956: Westinghouse Electric Corp., Sharon, Penn. Served as Quality Control Engineer, responsible for the design and development of special gauges and inspection equipment and for quality control systems analysis.

July 1952 - Aug. 1954: U.S. Air Force. Responsible for supervision of seven Air Force technicians and communications and electronics equipment utilized in reconnaissance aircraft.

Professional Affiliations

American Nuclear Society

WILLIAM P. GILLES - Staff Consultant - Instrumentation

Education

B.S. (E.E.) Loyola University, Los Angeles, California, 1953
Graduate studies in Transistor Circuit Theory, Electronic Circuit
Design Systems Engineering

Experience

1964 to Present: Aerojet-General Corporation. Mr. Gilles is responsible for the instrumentation system portion of the NERVA nuclear rocket engine program.

This work involves guidance of instrumentation program, determination of what measurements will be made and how, developing the electrical and instrumentation interfaces, development of instruments to make measurements in extreme environments and design, procurement, fabrication and installation of the electrical harness and all instrumentation for NERVA.

1961 - 1964: Aerospace Corporation. As a member of Advent Program Office, Mr. Gilles was responsible for the technical management of all the vehicle instrumentation and data handling, portions of the AGE, and Test Coordination. He coordinated the electrical power study and performed instrumentation and space experiment studies for the subsequent Synchronous ComSat study, and was responsible for electrical power subsystem and satellite stabilization on the Medium Altitude ComSat Program. This required a radiation damage study in conjunction with power supply responsibility on same program.

1953 - 1961: Design Specialist - The Martin Company; Senior Research Engineer - Rocketdyne; Flight Test Engineer - Douglas Aircraft Co.

Mr. Gilles' principal assignments during these years were the design of a multichannel programmable data handling system - Martin; development of an automatic programing and calibrating system - Rocketdyne; and the design and development of electronic and electromechanical control system - Douglas.

Publications

In 1965 Mr. Gilles presented a paper on Hot Gas Thermometry at the High Temperature Thermometry Seminar, Washington, D.C.

DAVID BUDEN - Staff Consultant - Systems

Education

B.S., Geophysics, Pennsylvania State University, 1952
M.S., Geophysics, Pennsylvania State University, 1954
Master, Business Economics, Claremont Graduate College, 1966
Graduate Studies in Mathematics, University of Cincinnati

Experience

1961 - Present: Aerojet-General Corporation. Mr. Buden is presently Manager of Systems Analysis, where he is responsible for nuclear rocket engine analysis. This includes development of complete mathematical models describing performance of various NERVA engine systems, analysis of the static and dynamic performance of NERVA, pre-test performance predictions, parametric studies, review of test plans, instrumentation and operating procedures, and post-test analyses.

During the period 1961 to 1964, Mr. Buden was Assistant Manager, Analytical Sciences Senior Department, Computing Sciences Division, with responsibilities for project management, planning and budgeting for two departments.

1955 - 1961: General Electric Company. Mr. Buden was Aircraft Nuclear Propulsion Department Supervisor, Control System Analysis Unit. His responsibilities embraced simulation and analyzing transient characteristics of complete aircraft power plants and their control systems, including simulation of the nuclear and thermodynamic characteristics of the reactor, the reactor control system, the turbomachinery control system. He established, through analysis and simulation, the stability and performance characteristics of the power-plant control system and the power-plant operating and check-out procedures.

1953 - 1955: U.S. Army. Mr. Buden was with the 193rd Ordnance Detachment, Camp Hanford, Washington. He worked as a physicist on the doppler network and electronic maintenance of Nike guided missiles.

1953: Department of the Interior, Washington, D.C. Mr. Buden worked in the Geophysics Branch, Geological Survey where he served as a geophysicist making and interpreting aero-magnetic surveys.

C. F. LEYSE - Staff Consultant - Support

Education

B.S. (Mech. Eng. with option in Physics) University of Wisconsin, 1948
Advanced studies in engineering and physics, Illinois Institute of
Technology, 1949-1950.

Experience

1963 - Present: Aerojet-General Corporation. Mr. Leyse is currently Manager, Safety Department, Nuclear Rocket Operations. In this capacity he is responsible for the management and technical direction of the safety program for development and test of the nuclear rocket engine. Mr. Leyse joined Aerojet in May 1963 as a Senior Nuclear Engineer in the REON Division and became Manager of the Nuclear Design and Operations Safety Department in September 1963. He was responsible for providing safety advice regarding the design and operation of nuclear rocket engines and the nuclear test, experimental, and fabrication facilities associated therewith.

1956 - 1959 and 1961 - 1963: Internuclear Company. He joined Internuclear as a senior engineer and subsequently served as its technical director, general manager and president. Initially he was responsible for nuclear reactor design. As technical director he provided overall technical management of design, development, and special studies involved in utilization of nuclear reactors for commercial and military power production, ship and aircraft propulsion, research and test, and for special purposes such as food preservation and activation analysis. As general manager and president he was responsible for promotional activities as well as overall management of the company.

1959 - 1960: Curtiss-Wright Corporation. Assistant manager and manager of the Nuclear Sciences and Engineering Department, which was engaged in nuclear reactor design and fabrication, fuel and materials development, and nuclear reactor operations.

1951 - 1956: Atomic Energy Division of Phillips Petroleum Company. Project engineer, staff engineer to the technical director, and as chief of reactor projects engineering. He participated in the startup and operation of the Materials Test Reactor, design of the Engineering Test Reactor, and was responsible for the engineering design, fabrication, and construction of the initial SPERT (Special Power Excursion Reactor Test) reactors.

1948 - 1951: Argonne National Laboratory. He was a design engineer and participated in the design of the Materials Testing Reactor and the CP-6 reactor.

Professional Affiliations

American Nuclear Society

L. E. DUKE - Study Project Engineer

Education

B.S. (M.E.), Missouri University, 1957
M.S. (Nuclear Eng.), University of California at Berkeley, 1960
MBA (Business Management), Sacramento State College, 1966

Experience

1964 - Present: Aerojet-General Corporation. As Program Manager of Nuclear-SWAT, Mr. Duke is directly responsible to the Nuclear Division for the development of a surveillance system for nuclear power plant on-line diagnostic, warning and control. This work involves forecasting, planning, and program development for the Nuclear-SWAT System. Mr. Duke is also Instrumentation and Control Coordinator for the Nuclear Division. His responsibilities in this area involve coordinating activities of all divisions in I&C.

As an Engineering Specialist in the Advanced Concepts Department of the Nuclear Rocket Operations, Mr. Duke was responsible for upgrading and optimizing the design of the NERVA Engine. He was also Project Coordinator for the Mission-Oriented Advanced Nuclear System Parametric Study, and a member of the systems task force optimizing the structural design of the NERVA Engine.

1963 - 1964: General Dynamics/Astronautics. Senior Research Engineer, Nuclear Technology. Mr. Duke was in charge of the development of a computer code that handled the problem of propellant heating and stratification from nuclear sources. He was responsible for radiation-effect and shielding studies for the MOL Space Station. He also acted as a consultant for nuclear-propulsion and clustering-rocket efforts.

1961 - 1963: Internuclear Company, Clayton, Missouri. As a Nuclear Engineer, Mr. Duke was responsible for nuclear, mechanical, and chemical engineering assignments in the advanced design of compact and mobile nuclear reactors, the design of experimental boiling-water mobile nuclear reactors, and the development of compact research reactors. His specific study areas included gaseous and liquid waste disposal; physics, hydrodynamics, and heat-transfer core design; shielding analysis; kinetics evaluation and licensing; and loop-stress and pressure-drop specifications.

1959 - 1961: University of California at Berkeley. Research Assistant, Nuclear Engineering Department. Mr. Duke assisted in an AEC research project involving transient boiling and steady-state bubble production experiments for SPERT application. He was responsible for void-volume research in sub-cooled nucleate boiling water.

1956 - 1959: McDonnell Aircraft Corporation and Emerson Electric Manufacturing Company, St. Louis, Missouri, and U.S. Navy. During this period, Mr. Duke was a Test Engineer for McDonnell, a Stress Engineer for Emerson and an Engineering Officer in the Navy.

Publications

Mr. Duke has some 13 publications which involve such related topics as Nucleate Boiling, Superheat Correlations, and The Handling of Engineers and Scientists.

Professional Affiliations

Member AIAA and ANS

Certified Professional Engineer (California)/Expert Examiner P.E. State Board

ARNOLD J. BERMINGHAM - Phase I Project Engineer - Analysis

Education

B.S., Mechanical Engineering, University of California at Berkeley, 1949

Graduate studies in Mechanical Engineering, University of California at Berkeley, 1951-1954

Experience

1958 to Present: Aerojet-General Corporation. Mr. Bermingham is Task Manager responsible for the supervision of the work of the subcontractor, Westinghouse Astronuclear Laboratory, to provide reactors for the nuclear rocket engines developed by the prime contractor, Aerojet-General, for the Space Nuclear Propulsion Office of NASA/AEC (1967 to present). Responsibilities include surveillance of the subcontractor work in the fields of reactor design, assembly, shipping, manufacturing, procurement, and capital equipment, to assure that the work of the subcontractor satisfies the technical, schedular, and budgetary requirements of the rocket program.

Mr. Bermingham was a Section Supervisor responsible for the Cold Flow Development test system, which was the first full size complete NERVA engine assembly. This project included the design and building of hardware unique to the engine, and the assembly of this hardware and the primary engine components into a complete test assembly. It also included planning, budgeting, and supervision of all project activities, conduct of the cold flow test program (with an unfueled reactor), and the issuance of the test program final report.

Subsequently responsible for the design and building of full scale engine mock-ups, and for their use in the testing program to develop the engine remote assembly/disassembly interfaces, and to develop the capability of

remotely installing the nuclear engine into its test stand by means of the Manned Control Cab/Engine Installation Vehicle.

At the San Ramon facility Mr. Bermingham was Assistant Manager of the Mechanical Engineering Department. Prior to 1962, Project Engineer responsible for the concept, design, fabrication, testing and installation of control rod system for the ML-1 Portable Gas-Cooled Reactor built for the U.S. Army and AEC. He was also responsible for the design of reactor fuel elements.

1956 - 1958: General Electric Company, Atomic Power Equipment Department. Mr. Bermingham reviewed and analyzed a dual-cycle, boiling-water reactor steam supply system (Dresden Nuclear Power Plant). Investigated the overall Dresden System flow, pressure, heat generation, and heat capacity parameters.

1954 - 1956: General Electric Company, Aircraft Nuclear Propulsion Department. Task leader for design of aircraft reactor cores, including mechanical design, heat transfer, fluid flow, thermal stress, materials, planning, and budgeting. Supervised a beryllium tube extrusion subcontract.

1950 - 1954: University of California Radiation Laboratory. In charge of design and construction of various experimental equipment projects, such as oil-cooled electromagnets, mechanical instruments, and high-pressure cloud chambers for research with atomic particle accelerators.

Professional Affiliations

Member of American Nuclear Society

American Institute of Aeronautics and Astronautics

National Society of Professional Engineers

American Society of Mechanical Engineers

Past Chairman of San Francisco Section, Machining Design Division,
American Society of Mechanical Engineers

Registered Professional Mechanical Engineer in the States of California
and Ohio

L. A. WELGE - Phase I Project Engineer - Support - Phase I Group Engineer -
Costs

Education

NSME, U.S. Navy Postgraduate School, 1948 - 1952
BSEE, U.S. Navy Postgraduate School, 1948 - 1952
BSME, University of California, Berkeley, 1939 - 1943

Experience

1960 - Present: Aerojet-General Corporation. Assured reliability of subcontractor and test facility items on NERVA project. As project representative, Mr. Welge conducted negotiations, accepted hardware, directed system tests, performed liaison and gave assistance to contractors and customer (NASA/AEC). Duties included assurance of adequate design, engineering, management, materials, process and contamination controls essential to development of the NERVA engine. He approved, reviewed or prepared nuclear test and project technical specifications, procedures and acceptance criteria; reviewed designs; drawings; stress analysis; failure mode analysis; fluid flow, thermodynamic and vibration analysis; work statement; and subcontractor progress reports and proposals.

Prior to the above assignment, Mr. Welge served on the Corporate Staff conducting market analysis, diversification studies, investment effectiveness and problem studies for aerospace, nucleonics and oceanic activities.

1958 - 1960: Papermate Manufacturing Company. Mr. Welge managed project with 5 to 15 scientists, engineers and highly skilled specialists conducting micro-dimensioned R&D project requiring tightest optical precision. Duties included statistical planning and analysis, control and analysis of experiments, reliability of predictions and analysis, management of R&D lab, and market tests and studies utilizing statistically sophisticated interpretation and analysis.

1956 - 1958: U.S. Chem. Mill Corporation. Mr. Welge directed three medium-sized aerospace plants involving programs for Titan, Bomarc, B-58 and others in difficult-to-machine parts and R&D on exotic aerospace materials. He developed a sophisticated quality control program which resulted in a reduction in rejection rates from 22% to 3%.

1952 - 1956: MINS, U.S. Navy. Chief Engineer and program manager for various Navy projects including Regulas, Polaris, and Nuclear submarine manufacturing and support system.

1943 - 1952: U.S. Navy. Mr. Welge was Chief Engineer of the U.S.S. Duluth and Executive Officer of the U.S.S. destroyer Yarnell. Highest rank obtained - Lt. Commander.

J. H. ALTSEIMER - Phase II Project Engineer - Systems Analysis

Education

B.S.M.E., University of Wisconsin, 1941
Studies in Aeronautics, Johns Hopkins University, 1941-43
M.S.A.E., California Institute of Technology, 1946
Engineer Degree in Aeronautics and Jet Propulsion, California
Institute of Technology, 1948
U.C.L.A. Extension Course, Status of Controlled Fusion Research, 1962
Nuclear Reactor Operators Training Course, 1966

Experience

1951 to present: Aerojet-General Corporation. Mr. Altseimer is currently assigned as Engineering Supervisor, Technology Engine Analysis Group, and is responsible for predictions of Technology Engine performance in planned test programs, analytical support for engine and test facility system developments, and supervision of analysis of engine performance immediately after tests. As Engineering Supervisor of the Data Analysis Group, his responsibilities included analysis of performance from a systems standpoint for NRX-A3 and NRX/EST nuclear reactor and engine tests. He was principal engineer in charge of Liquid Rocket Operations In-Space Cryogenics, Advanced Program Office.

While Senior Department Manager of Propulsion Technology, LRO, he was responsible for feasibility studies of new liquid-propulsion systems or components, and propulsion aspects of a Post-Nova Vehicle Study. He also directed experimental programs for saturated propellant systems and expandable nozzles. Included were several applications of LH_2 , radio-isotopes, solar-energy propulsion, and a liquid-core nuclear reactor engine.

As Head, Engineering Physics Section, LRO, he supervised applied research on heat transfer, combustion, thrust nozzles, pressurization systems,

new propellants, and directed an intensive test program for determination of performance of H_2O_2 /pentaborane propellants. In LRO Preliminary Design Department, he conducted design studies of cryogenic and storable-propellant propulsion systems.

1946 - 1947: Research Engineer, Liquid Rocket Section. Conducted H_2O_2 rocket performance experimental studies.

1946: Bell Aircraft Corp. Conducted rocket thermochemical study as Senior Research Engineer, X-1 airplane project.

1941 to 1945: The Martin Company. Production and design experience on airframes was acquired as Senior Aircraft Stress Analyst.

Inventions

Expandable-Nozzle Concept

STANLEY K. YODER - Phase II Project Engineer-Literature Support

Education

B.S. in Industrial Design from University of Southern California, 1951
Graduate studies in Nuclear Physics, Management Systems and Logic

Experience

1955 to Present: Aerojet-General Corporation. Mr. Yoder is presently the Assistant Manager of NERVA Instrumentation. In this capacity he is in charge of various technical functions concerned with the development of radiation tolerant instrumentation systems and their application to the NERVA engine and the NERVA test facilities.

As Manager of NERVA Accessories Department during the period between 1962 - 1964, he was concerned with the overall design, analysis, and testing of NERVA diagnostic system components and with the use of radiation tolerant explosives in a possible countermeasure system.

Previous assignments also included the preliminary designs of, and analysis of control components and subsystem required in the operation of various nuclear rocket engine systems and direction of the development of a cryogenic mass flow meter.

Mr. Yoder has been responsible for the design of various fluid sequencing control devices used in chemical rocket engine systems.

1951 - 1955: James-Pond-Clark and Hydraulic Units Inc. With James-Pond-Clark, Mr. Yoder was concerned with the design and development of aircraft fluid control components.

J. A. VREELAND - Phase I Group Engineer - Nuclear Analysis

Education

Ph.D, Physics/Mathematics, University of Wisconsin, 1955
M.A., Physics/Mathematics, University of Wisconsin, 1951
B.S., Cum Laude, Presbyterian College, Physics/Mathematics, 1949

Experience

1962 to Present: Aerojet-General Corporation. Dr. Vreeland's responsibilities at Aerojet-General include the direction of the nuclear analysis effort required by Nuclear Rocket Operations. In addition to support of the NERVA program, this effort includes: support to other Aerojet-General operations including Idaho Nuclear Corporation, Aetron, and Nuclear Products and Services; support to corporate sponsored study programs in Advanced Concepts; and operation of the Dosimetry Laboratory for the development of improved dosimetry techniques. In support of the NERVA program, NRO nuclear analysis develops criteria for the NERVA shields, designs those shields external to the pressure vessel, predicts environment for engine ground tests and flight configurations, and supports component design with detailed calculations of nuclear heating rate and dose accumulations. Dr. Vreeland was on the staff of the Nuclear Rocket Propulsion Symposium at the University of Florida sponsored by the National Science Foundation and delivered a lecture series to the Sixth Annual Faculty-Student Conference of Associated Midwest Universities.

1960 - 1962: Rocketdyne. Dr. Vreeland directed the Rocketdyne effort in the overall design of very large nuclear rocket engines. In addition, he directed the reactor analysis necessary for the design of all nuclear rockets. Teaching activities included the reactor portion of a company-sponsored 60-hour course in nuclear rocket theory and courses in Modern Physics and Nuclear Physics at the University of California at Los Angeles.

1955 - 1960: Westinghouse, Atomic Power Department. The technical direction for a reactor physics group whose responsibility it was to maintain a contemporary library of physics constants by using recent cross-section measurements and by performing calculations based on the various nuclear models of theoretical physics; the technical responsibility of reactor analysis for particularly challenging situations as exemplified by the Westinghouse Variable Loading Test Reactor; planning and execution of related experimental program of the Pennsylvania Advanced Reactor were each portions of his responsibility at Westinghouse. The requirements for these jobs included a familiarity with the potential of reactor experiments; and a competence with both analog and digital computers.

Publications

Dr. Vreeland has 6 publications dealing with the related topics of neutron environment and fuels measuring facility.

Affiliations

Registered Professional Nuclear Engineer
American Physical Society
American Nuclear Society
Atomic Industrial Forum
American Institute of Aeronautics and Astronautics
Sigma Xi

K. SATO - Phase I Group Engineer - Thermodynamics Analysis

Education

B.S., Chemical Engineering, California Institute of Technology, 1951
M.S., Chemical Engineering, California Institute of Technology, 1952
Ph.D., Chemical Engineering, California Institute of Technology, 1955

Experience

1955 - Present: Aerojet-General Corporation. Dr. Sato is active in the direction of analytical and design studies in fluid dynamics and heat transfer related to nuclear rocket engines and associated support facilities. He did research in heat transfer in porous materials with application to transpiration cooling in rocket nozzles, made experimental studies of heat transfer to various fluids for characterization as regenerative coolants, and performed gas dynamic studies with shock tubes.

Publications

"Materials Transfer in Turbulent Gas Stream: Influence of Shape on Evaporation of Drops of n-Heptane," Ind. Eng. Chem., 46, 870 (1954) (with Hsu and Sage).

"Temperature Gradients in Turbulent Gas Streams: Recovery Factors in Steady, Uniform Flow," Ind. Eng. Chem., 47, 918 (1955) (with Opfell and Sage).

"Temperature Gradients in Turbulent Gas Streams," Ind. Eng. Chem., 48, 2218 (1956) (with Hsu and Sage).

"Material Transfer in Turbulent Gas Streams: Effect on Turbulence on Macroscopic Transport from Spheres," Ind. Eng. Chem., Chemical and Engineering Data Series, Vol. 2, No. 2, 263 (1958) (with Brown and Sage).

Professional Affiliations

American Rocket Society
Combustion Institute
Sigma Xi
Tau Beta Pi

C. E. DIXON - Phase I Group Engineer - Material Evaluation

Education

B.S. (Physics) Washington State University, 1942
M.S. (Physics) Washington State University, 1948
D.Sc. (Physics) Carnegie Institute of Technology, 1951

Experience

1963 - Present: Aerojet-General Corporation. Dr. Dixon is presently assigned as Supervisor for Advanced Material Development work. His duties consist of technical evaluation of all phases of material research and development on the NERVA Program. Particular assignments include reactor materials liaison with Westinghouse Astronuclear Laboratory, cryogenic and high temperature irradiation research in structural alloys, polymers and elastomers. High temperature irradiation studies include the materials: AISI 347, Hastelloy X, Inconel 625, Inconel 718, Waspaloy, and Rene 41. Cryogenic irradiation studies include the above materials and aluminum and titanium alloys.

1951 - 1963: Atomics International. Group Leader, Ceramics, Atomics International and North American Aviation Science Center. Mechanical testing of high temperature materials (BeO, Graphite). Crystal growth and purification by Czochralski method, float zone refining and others (UC, refractory metals, doped alkali halides, and rare earth fluorides), metallography, X-ray diffraction and electron microscopy.

As Group Leader of Solid State and Metallurgy, Dr. Dixon provided technical direction and evaluation for a group of 30-35 technical people. This group was engaged in basic and applied research for the U.S. Atomic

Energy Commission in the fields of radiation damage, lattice defects, mechanical properties and the electronic structure of metals. Research included: radiation damage, creep, and mechanical properties of graphite, aluminum oxide and beryllium oxide. A company-sponsored solid state electronic program was initiated. Dr. Dixon also participated in outlining radiation damage problems in electronic systems B70 and SNAP 8.

Supervisor, Radiation Effects and Mechanical Properties Unit. Mechanical property research on graphite, titanium, and refractory oxides at high temperature. During this period, Pluto research program on potential high temperature materials for use in a nuclear ramjet was introduced. Led the proposal efforts and supervised a major portion of the work which was at \$1,000,000 - \$1,500,000 per year level.

Senior Physicist - Radiation damage in solids; lattice defects in solids. Pioneered with associates in using charged particles from cyclotrons and electron accelerators for radiation damage and lattice defect studies in metals. This work has been extended by many laboratories throughout the world and continues to be a strong important effort at Atomics International.

1948 - 1951: Carnegie Institute of Technology: Research Assistant and Graduate Student, Physics Department. Approximately half-time research during this period in solid state physics (metals). Thesis research involved X-ray studies of plastic deformation in single crystal ordered Cu_3Au . The work was supervised by Professor J. S. Koehler.

Professional Affiliations

American Physical Society
American Society for Metals
American Nuclear Society
Sigma Xi

Publications

Dr. Dixon has 9 publications to his credit dealing with such related topics as radiation effects on structural material and polymers, radiation embrittlement, high energy radiation effects, and generalities of radiation damage.

D. E. DEUTSCH - Phase I Group Engineer - Radiation Effects

Education

B.S. (Chemistry) Lafayette College, Easton, Pa., 1939

M.S. (Metallurgy) Carnegie Institute of Technology, 1949

Completed all course requirements for Ph.D. degree from Carnegie Institute of Technology in 1949.

Attended graduate courses in high-temperature and creep at Massachusetts Institute of Technology in 1954 and in the mechanical behavior of metals at high temperatures at University of California, Berkeley in 1959.

Experience

1967 - Present: Aerojet-General Corporation. Mr. Deutsch presently is the Manager of Radiation Effects, Nuclear Rocket Operations. He has held this position since 1967. He is responsible for the evaluation of radiation environments for instrumentation, components, and metals planned for use on the NERVA engine and reactor. He also is responsible for obtaining existing radiation data at NERVA environmental conditions, predicting the reliability, usable life and safety levels for candidate materials and components, and deciding if additional testing is necessary to prove performance.

1958 - 1966: Aerojet-General Nucleonics. As technical staff member of Advanced Concepts, he was responsible for evaluation of advanced nuclear power and propulsion systems and nuclear fuel cycles. During this period, he also was assigned to the technical staff to the Senior Vice President, Nuclear Products and Services Division.

As manager of the Nuclear Technology Division, he supervised nuclear research and engineering on compact nuclear reactors and the engineering and production of fuel elements for NERVA and other gas-cooled reactors.

As manager of the Metallurgy Department, he was responsible for research and radiation testing of nuclear fuel elements and capsule and loop experiments.

1956 - 1958: Sierra Metals Division, American Marietta Corporation, Menlo Park, California. He and three others founded this new division. During this period he also worked for the Fansteel Metallurgical Corporation. With both firms he supervised research, engineering and production of refractory metals, refractory compounds, and composites.

1952 - 1956: Atomic Energy Commission, Washington, D.C. He supervised and coordinated materials and metallurgy research for the AEC-USAF nuclear-powered aircraft program, including high-temperature fuel element, moderator, control rod, and structural materials and radiation testing.

Mr. Deutsch studied physical metallurgy of uranium, lithium, cadmium, and other special nuclear materials at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico from 1949 to 1952.

Publications

LA-1180, "Development of Techniques for the Fabrication of Uranium" (LASL, 1951)

"The Operation of a Pumped Boiling Rubidium Loop," D. E. Deutsch, et al (1961)

"Centrifugal Creep Testing of Pure Aluminum," D. E. Deutsch, R. S. Carey, J. L. Hill (Transaction of ASM, Vol. 54, 1961)

"The Radiolysis of Liquid Ammonia," E. G. Carpenter and D. E. Deutsch (1963)

Professional Affiliations

American Society for Metals

American Nuclear Society

American Institute of Mining, Metallurgy, and Petroleum Engineers

Patents

Design concept for a nuclear reactor capable of producing chemical reactions. U. S. Patent number 3,334,020, granted 1 August 1967.

Development of high-temperature, oxidization-resistant, cobalt-base alloys. U. S. Patent number 3,202,506, granted 24 August 1965.

T. O'CALLAGHAN - Phase I Group Engineer-Stress - Strain and Vibration

Education

Sc.D., Doctor of Science in Vibration Engineering, Swiss Federal
Institute of Technology, Zurich, Switzerland, 1953
B.E., Bachelor of Mechanical and Electrical Engineering, University
College, Dublin, Ireland, 1943
B.L., Barrister at Law, Kings Inns, Dublin, Ireland, 1958

Experience

1959 - Present: Aerojet-General Corporation. Currently Senior Engineering Specialist on the Technical Staff of the Manager, Structures Section, Engineering Department, Nuclear Rocket Operations. Functions include (1) design of new altitude-simulating test facilities for nuclear reactors and of improvement to the existing facility; (2) data analysis of vibration, stress and displacement parameters measured during trial runs of the existing test facility and the correlation of variations of these parameters with measured system temperature and pressure variables; (3) recommendation of additional locations to measure these parameters to disclose more clearly their inter-relationship; (4) the prediction of the time dependence of test parameters based on proposed test sequences; (5) the establishment of control parameters and methods for measuring these to assure the capability of taking real-time corrective action to shut down a test in the event of system malfunctions. Dr. O'Callaghan has been a member of the Test Instrumentation Limit Team in this connection and has functioned in the Test Diagnostic Center during tests, following stress, vibration and displacement parameters on recorders and cathode ray oscilloscopes to assure the safe and reliable functioning of the costly test facility during trial runs. He has monitored in this manner the vibrations of system piping under flow induced transients, for example, the facility helium and steam lines; the latter leads from chemical steam generators to the diffuser of the altitude facility and has been subjected to large transient vibrations as a result of the sudden start characteristics of the steam generators and the relative flexibility of the steam line. He recommended

locations for snubbers for the optimal damping of the steam line and also recommended the monitoring of gimbal bellows angulation on the line by means of displacement gages to assure that the gimbals were not bottomed out. He has also been concerned with waterhammer problems in the piping of the cooling water and fire extinguishing (safety) system and recommended sequencing the opening and closing operations of the valves to minimize the waterhammer problem which had caused process piping to fail. He has also been concerned with the cyclic fatigue analysis of the high temperature stainless steel exhaust duct, where metal temperatures are expected to reach 1400°F and transient thermal stresses will be high, and also with a thermal ratcheting problem in another stainless steel pipe in the system in which there is a large circumferential temperature gradient.

Dr. O'Callaghan is also concerned with the review of acoustical data taken during preliminary tests to assure that noise levels during later hot firings of the reactor will not exceed permissible levels both from the standpoint of inducing excessive fatigue stresses in the mechanical components of the system and significantly also of the capability of the diagnostic and control instrumentation to function properly in high acoustic environments.

1953 - 1956: Electro-Chemicals Division, E. J. du Pont, Niagara Falls, New York. As assistant to the Plant Technical Manager and later as Group Leader of the Sodium Cell Development Group, Dr. O'Callaghan made a detailed study of the physics, hydrodynamics and electrochemistry of the fused salt electrolysis method for the production of sodium at temperatures up to 1200°F. This study led to several improvements in sodium cell design leading to more efficient higher amperage units. He developed the application of high temperature ceramic spacers (to maintain adequate clearances between the cell diaphragm and the electrodes) and suggested the development of a high temperature hydrometer for the determination of cell bath density. He also studied the magnetohydrodynamic aspects of the convective stability of vertical pipes of sodium in connection with the settling out of impurities. Two patents were filed in connection with his work on sodium cells in connection with the configuration of graphite anodes.

1949 - 1952: Maschinen-Fabrik Oerlikon, Zurich, Switzerland. Design Engineer in the Gas Turbine Department. Engaged in the stress and vibrations analysis of centrifugal compressors, heat exchangers, and gas turbines for commercial power stations. Heat flow and thermal stress analysis of components.

Publications

Dr. O'Callaghan has some 21 publications in engineering fields.

J. S. GODDARD - Phase I Group Engineer - Reliability and Quality Control

Education

B.S., Chemical Engineer, Oklahoma State University, 1950

Summary

Mr. Goddard's twelve years experience in aerospace at Aerojet-General Corporation has given him a broad background in all areas of product assurance, including reliability engineering, quality engineering, design, test planning, and management. Six previous years of experience have added to his general engineering and administrative capability.

Experience

1955 to Present: Aerojet-General Corporation. For the past twelve years, Mr. Goddard has been almost continuously engaged in design review, reliability and qualification testing, performance and failure analysis, and reliability analysis, including component reliability and safety trade-off studies for the NERVA nuclear engine and the Apollo Service Module engine. For two years, Mr. Goddard has been engaged in systems analysis for major proposal efforts such as the post-boost propulsion system (PBPS), long-range mortar, Voyager engine and the captive air bubble ship. During ten years in the solid rocket operations of Aerojet-General Corporation, Mr. Goddard was engaged in all aspects of solid rocket technology from applied research through production. He has held supervisory positions in design review, test, analysis, and quality control planning in the Polaris program. He served for one year as manager of the Reliability Department for the Air Defense Rockets Division in Sacramento. He was chairman of the Polaris Gage Committee, and head of the Returned Products Team. During four years with the Air Force, he served as squadron engineering officer for aircraft maintenance and overhaul, engineering test pilot for production aircraft, instructor pilot, and flight leader,

attaining the rank of Captain. He is presently manager of a space engine parametric design study contract.

1951 - 1955: U. S. Air Force. During this period, Mr. Goddard served as squadron engineering officer to aircraft maintenance and overhaul, engineering test pilot for production aircraft, instructor pilot, and flight leader, attaining the rank of Captain.

STANLEY H. KLEIN - Phase I Group Engineering - Safety Analysis

Education

B.S. (Physics), Lafayette College, Easton, Pennsylvania, 1952
On-the-job training program, Argonne National Laboratory, 1952-1953
Reactor Operations Training Program, Curtiss-Wright Corporation, 1959

Experience

1964 - Present: Aerojet-General Corporation. Mr. Klein is engaged on the nuclear and radiation safety aspects of the NERVA program and is participating in safety evaluation for the NERVA-engine test program. He is making a continuing evaluation of the low-power critical facility and operations at the engine-test facility.

1961 - 1964: Internuclear Company, St. Louis. At the Internuclear Company where he was Manager of the Kyoto University Research Reactor Project, he was in charge of U.S. work to establish the preliminary design, technical specifications, and physics calculations for the basic core configuration and biological shield. He assisted the Japanese in evaluation of the final design for submittal of a hazards analysis report to the Japanese AEC. As the on-site engineer, he was responsible for tests of all the reactor systems and supervised the initial criticality and power testing.

1960 - 1961: U.S. AEC. Mr. Klein was formerly employed by the U.S. AEC and was responsible for evaluating (from the hazards standpoint) reactor proposals and reactor modifications with respect to design, operation, containment, and location with regard to public health and safety. He prepared hazard evaluations on critical assemblies and research, power, and production reactors for presentation to the Advisory Committee on Reactor Safeguards.

1956 - 1960: Curtiss-Wright Corporation. His experience was concerned with operation of the research reactor and hot laboratory facilities as Manager,

Experimental Operations Division of the Nuclear Science and Engineering Department. He was directly involved in preparing a hazards summary report for the expansion of the reactor facility from 1-Mw to 4-Mw operation. He also actively participated in decontamination of the hot-cell facilities and disassembly of the research reactor when Curtiss-Wright discontinued its nuclear operations.

1952 - 1956: E. I. du Pont de Nemours & Company. Mr. Klein was a member of the reactor startup team at the AEC Savannah River Plutonium Production Plant. He was later assigned as reactor-area physicist, and gained considerable experience in measurements of the reactor flux distribution and rod worth, and in other problems associated with reactor operation.

ALLEN T. GREEN - Phase II Group Engineer - Applicability and Development

Education

B.S. (Aero Engineering), University of Illinois, 1956
Postgraduate work in analog and digital computer programming, strain
gage techniques and high-temperature measurements. UCLA
Postgraduate course in Applied Mechanics - Sacramento State

Experience

1961 - Present: Aerojet-General Corporation. As SWAT Program Manager Mr. Green has been responsible for approximately one-half million dollars of contracts on SWAT programs. He has been engaged in the development and use of the stress-wave analysis technique since its inception at Aerojet. Mr. Green's well-rounded background in instrumentation and structural testing has qualified him for concentration in other areas such as temperature, energy and strain measuring devices, aerodynamic heat simulation on rocket motors, specialized instrumentation development, full scale nozzle thermal shock simulators, and acoustical analysis of structural components.

1956 - 1961: General Dynamics - Convair. Mr. Green's experience prior to employment at Aerojet-General Corporation encompassed the following areas of endeavor: test planning; instrumentation and calibration methods; automatic data reduction and equipment and techniques for telemetered and airborne recorded data; temperature, load and data recording; system programming, stress analysis; and high-temperature structural test laboratory operations.

Publications

Articles by Mr. Green have been presented at the Society of Plastic Engineers and the Society for Experimental Stress Analysis.

Professional Affiliations

Mr. Green is a member of ASTM, SESA, WRSGC and AEWG.

He is currently Chairman of the Western Regional Strain Gage Committee and Secretary of the Acoustic Emission Working Group.

LOUIS G. DEL VALLE- Phase II Group Engineer - Instrumentation

Education

Undergraduate studies in Electronic Engineering, Capitol Radio
Engineering Institute, Washington, D. C., 1950
San Francisco City College, 1952
Contra Costa Junior College, Richmond, California, 1953
University of California at Berkeley, 1962
San Jose State College, Physics and Mathematics, 1963

Experience

1958 - Present: Aerojet-General Corporation, San Ramon, California,
Senior Design Engineer. Currently, Mr. Del Valle is responsible for URIPS
power conditioning unit, development and testing and low-frequency electro-
magnetic transmission analysis and experimental work.

He was Task Engineer responsible for the design and development of a
technique to measure the vapor viscosity of alkali metals at elevated tempera-
tures, and for the design and fabrication of the ion source power supplies in
the Plasma Research Program accelerator.

Project Engineer responsible for the analysis, design, development and
fabrication of the instrumentation and control system for the Pulse Power
Facility at Aerojet for use in the Plasma Research Program.

Task Engineer responsible for the analysis, design, development and
testing of the specialized in-pile instrumentation, control servo systems, and
the specialized power distribution system for the Hydrazine Process Development
Program in-reactor processing loop. Project Engineer responsible for the
analysis, design and development of the instrumentation and control systems
for the Component Test Loop of the Hydrazine Process Development Program.

Project Engineer responsible for the design and fabrication of the Turbine Compressor Overspeed Bypass Controller installed at the Gas-Turbine Test Facility, Fort Belvoir, Virginia. Project Engineer responsible for test evaluation of the instrumentation system used on the Gas-Turbine Test Facility at Fort Belvoir.

Task Engineer responsible for the analysis and design of the process and analysis instrumentation during the design phase of the GTTF-1A modification. Task Engineer responsible for a portion of the design, development fabrication, and specification of prototype process instrumentation subsystems and control systems used in the ML-1 Program; designed and developed the ML-1 3000 watt dc to ac Emergency Power Inverter; participated in the analog analysis of the ML-1 system and in the design and development of the control-servo systems; responsible for the design of the shock and vibration instrumentation system used in the ML-1 System Transportability Study.

Task Engineer responsible for the design and development of the control instrumentation for the Nuclear Nitrogen Fixation Reactor Program; participated in the design of the process and control instrumentation of the Gas-Cooled Reactor Experiment (GCRE).

Previously was responsible for the design and fabrication of test instrumentation used on a classified government program; participated in the design and development of a mass gamma radiation detection system used in the Pacific Test Area; in the design and development of complex photosensitive equipment, packaging registration controls, and other control and test equipment; responsible for the design of the radio frequency source and control system used in the first food sublimation-vacuum distillation process.

1955 - 1958: Friden Corporation, San Leandro, California, Electronics Technician, Instrument Design.

1953 - 1955: D. R. Vinson Company, Oakland, California, Electronics Engineer.

Patent

Disclosure of Invention, AGN-190, Nuclear Reactor Core Diagnostic System.

Publications

Transportability Study, ML-1 Nuclear Power Plant (with J. W. Blakley, et al), IDO-28555 (April 1960); Underwater Communication System (with R. Cribbs, et al), IRD Final Technical Report 8711-31-7501, 30 November, 1966; A Covert Diver Countermeasure System, L. G. Del Valle, et al, PD 67-6, (April 1967).

H. BENENSON - Phase II Group Engineer - System Acquisition

Education

B.S. (Mathematics, Physics, Chemistry), University of Minnesota, 1948
M.A. (Statistics, Mathematics), University of Minnesota, 1949
Candidate for Ph.D. (course work completed at University of Minnesota;
major - statistics; minor - engineering)

Teaching

U.C.L.A. - industry course in reliability, 1958
U.C. Extension, Davis - statistics, 1959-1960
Sacramento State College - Assistant Prof., Mathematics, Statistics,
Operations Research, 1960-present

Experience

1959 - Present: Aerojet-General Corporation. Mr. Benenson is presently assigned to Systems Analysis Section of Nuclear Rocket Operations as a Senior Engineering Specialist working on developing, validating and applying computing programs for performing dynamic controls analysis for NERVA engine tests. He carried out the accuracy evaluation of data acquisition system at Nuclear Rocket Development Station (Jackass Flats, Nevada) and performed mathematical and statistical analysis to support the test program.

Prior to NERVA assignment, Mr. Benenson was assigned to the Polaris and Minuteman programs where he served in several supervisorial and technical capacities as a Technical Specialist. He was in charge of a non-destructive test analysis activity, supervisor of a systems analysis section, and acted in a staff capacity to the Division Manager of Reliability and Quality Control.

1956 - 1959: Marquardt Aircraft Company. Mr. Benenson was a member of Technical Staff, advisory to the Chief Engineer assigned to the Systems Analysis

Section. He performed pneumatic and acoustical controls analysis, statistical and optimum analysis of testing, and was in charge of the reliability program.

1953 - 1956: Northrop Aircraft Company. As a Senior Engineer, Mr. Benenson was supervisor of data analysis section in the engineering division to support the SNARK missile design and test program.

1950 - 1953: U.S. Air Force Procurement Division, Assistant Chief Quality Assurance Branch. Mr. Benenson was in charge of contractor evaluation and setting up procurement standards with respect to quality, reliability, and cost efficiency for Air Force contractors in the Western Procurement District. Acted as staff assignment to commanding officers with respect to statistical and analysis types of problems and presentations.

L. G. SCHWIEGER - Phase II Group Engineer - Inspection Methods
Phase I Group Engineer (Backup) - Reliability and Quality
Control

Education

B.S., Chemical Engineering, Iowa State University, 1950
Graduate Work, Electrical Engineering, University of Minnesota, 1954
Idaho State Extension Courses in Nucleonics, 1957
IBM Computer School, 1958
Management and Supervision Courses, American River College, Sacramento,
California, 1962-1964
EAI Simulation Analysis, 1964
Transistor and Circuit Analysis Courses, American River College,
1963-1966

Experience

August 1959 - Present: Aerojet-General Corporation. As Senior Technical Specialist for development of NDT (Nondestructive Testing) methods to test rocket assemblies and components, Mr. Schwieger is responsible for building a sonic resonator to test honeycomb structures in the Titan Ablative Skirt. He acts as consultant on many other areas of metallic and non-metallic testing, and is principally concerned with designing test instrumentation when no commercial units are available.

While Supervisor of Measurement Standards Laboratory, including both mechanical and electrical areas, his engineering responsibility included procedures used to calibrate instruments and gauges at the Sacramento Plant, provide technical support for primary and secondary calibration laboratories, maintain traceability to NBS (National Bureau of Standards) for all measurement standards and provide optimum accuracy ratio for all calibration methods, and review all new installation of measurement equipment and provide an optimum method for maintenance and calibration of this equipment to assure reliable data taking.

Mr. Schwieger previously had responsibility for organization and supervision of the Solid Rocket Process Instrument Program, and was responsible for all process instrumentation connected with the production of a solid rocket motor. This covers both the areas of development and application.

July 1956 to August 1959: Phillips Petroleum Company, Atomic Energy Division, Idaho Falls, Idaho. Mr. Schwieger was group leader, Instrumentation Section, Chemical Process Facility. In this capacity he was responsible for the design, development and test of the following instruments: 3-beam spectrophotometer; high frequency oscillator; liquid level column follower and associated servo loops; and simple photometers.

July 1953 to July 1956: General Mills, Minneapolis, Minnesota. As Project Engineer, was responsible for design, development and test of two-wire arctic trail marking system to guide vehicles in a confined trail under zero visibility, radiosonde data computer to compute and record temperature, humidity and air pressure from radiosonde balloons, and rate of climb simulator to calibrate aircraft instruments.

July 1950 to July 1953: Ladish Company, Metallurgical Department, Milwaukee, Wisconsin. Associate Engineer for nondestructive testing. Primary responsibility was to develop a nondestructive method of testing turbine rims for jet engines. An ultrasonic immersion instrument was developed complete with servo loops to move the inspection crystal through five degrees of freedom.

Achievements

- 1953 - Ultrasonic immersion unit for inspecting turbine rims.
- 1955 - Radiosonde data computer for gathering meteorological data.
- 1956 - Two-wire trailmarking system for arctic navigation.
- 1958 - 3-beam spectrophotometer for monitoring uranium.
- 1960 - Continuous mix production plant for making solid rocket propellant.
- 1963 - Designed electromechanical microencapsulator.

1966 - Reorganized and upgraded Measurement Standards Laboratory to meet NASA standards

1967 - Designed Automatic Sonic Resonator System to test ablative skirt.

Patents

Ultrasonic Gas Disengager for Raffinate Streams, No. 3, 044, 236 Simple Photometer for Measuring Uranium Concentration, No. 3, 044, 235

Patent Pending

Electromechanical Microencapsulator for encapsulating toxic or highly explosive material in an inert coating.

ROBERT SIEV - Phase II Group Engineer - Instrumentation Candidates

Education

BScE, New York University, 1948
MBA, University of Southern California, 1962

Experience

1958 - Present: Aerojet-General Corporation, SNAP-8 Division.
Instrumentation Engineer. In charge since 1964 of the entire 700-channel instrumentation and data acquisition system for the non-nuclear operational SNAP-8 system. Develops techniques and components for liquid metal service. NERVA Program, 1961 - 1964. Supervisor, in charge of instrumentation for this program. Developed the radiation resistant strain-gages and pressure transducers. 1959 - 1960, Spacecraft Division. Project Engineer for new pressurization system using solid propellants as source of inert gases. 1958, Chemical Division. I&C Engineer. Design of high-energy fuel pilot plants.

1956 - 1958: C. F. Braun. Instrument Engineer in the Chemical Engineering Department.

1951 - 1956: Fischer & Porty Company, Hatboro, Pa. Project Engineer. Chlorination, sewage, waste disposal, and water plant instrumentation.

1951: Allied Processes, Inc., New York. Design Engineer of Chemical Plant system.

1950 - 1951: Brooklyn Yarn Dye Co., New York. Chemical Engineer.

Publications

"Mass Flow Measurement", Instruments and Control System, June 1950
"SNAP-8 Instrumentation", Aerospace Instrumentation Symposium, ISA Convention, October 1965

Professional Affiliations

AIChE, SCMA and ISA - Committee Member on Standards for the specification, installation and operation of turbine type flow transducers.

b. Backup Personnel Resumes

(Resumes are positioned in descending project organizational order)

LESLIE E. WHITE - Study Project Engineer (backup)

Education

B.S. Chemistry, University of Denver, 1948
Naval Engineering (Accelerated) - University of Dubuque, 1944-1945
250KW AGNIR Reactor Operator Training - Aerojet-General Nucleonics

Experience

1955 to Present: Aerojet-General Corporation. Mr. White's current assignment involves technical staff coordination in the areas of surveillance and inspection equipment, LMFBR planning, and remote handling development. Previously he was assigned as a Manager, at the Nuclear Rocket Development Station, Jackass Flats, Nevada. There he was manager of the Engine Maintenance Assembly and Disassembly (MAD) Operations necessary for the development of the NERVA Nuclear Rocket Engine. The facility complex involved provides for receiving, assembly, checkout, handling, transport, recovery, disassembly, postoperative examination and disposal of the nuclear reactor and engine development hardware. Further, it includes all functions encompassing the equipment associated with normal handling, remote operation, instrumentation, shop operations, maintenance and repair. This assignment provides for the overall technical, fiscal, operational and administrative management for an integrated multi-corporation work force. Responsible representative of the operating contractor for facility management safety, development and utilization of conventional and specialized remote handling systems, equipment and machinery. As Senior Department Manager at the Site, he was responsible for the overall technical, fiscal and administrative supervision and direction of engineering and scientific personnel and subcontractor activities. Activities included development of criteria, design and acquisition of all NERVA ground support equipment and tooling for NRDS use; development of NRDS facility criteria; A-E design approval responsibility and facility development planning.

1954 - 1955: Herrick L. Johnston, Inc. As a Project Engineer for H. L. Johnston, Inc., Mr. White was responsible for design, development, field installation and operation checkout of cryogenic systems and equipment - hydrogen liquifiers, refrigerators, storage dewars, vacuum jacketed transfer systems, and high pressure liquid nitrogen and oxygen cascade pumping systems.

1951 - 1954: National Bureau of Standards. As a Physical Chemist, Sr. Project Leader, Mr. White's tasks included research and development of methods and techniques for catalytic conversion of normal hydrogen to para-hydrogen; modification of production liquefier for maximum conversion efficiency; design development of analytical methods; and installation, activation and operation of two production nitrogen liquefiers.

1948 - 1951: Naval Powder Factory. For NPF, Mr. White was an Assistant Project Chemical Engineer and was responsible for research and development for synthesis of new and exotic organic explosives and related compounds.

Publications

Mr. White has 8 publications related to nuclear reactor handling and environment. These articles were published in AIAA and ANS Journals.

A. H. FLAGG - Phase I Project Engineer (backup)-Analysis

Education

B.A., Physics, University of California, Los Angeles, 1949
M.A., Physics, University of California, Los Angeles, 1951
Reactor Engineering, ORSORT, 1955 - 1956

Experience

1956 to Present: Aerojet-General Corporation. Senior Engineering Specialist, NRO Technical Staff. He is presently involved principally in the backup FFTF Core Concept. He has participated in other FFTF activities including FFTF Fuel Handling and Phase II Conceptual Design. He was active in preliminary design of NERVA II engine, preparation of test and flight model specifications, and program planning for development requirements including facility acquisition and utilization. Conducted advanced concept studies of nuclear rocket systems for improved performance objectives; work involved support of multiple-nozzle experimental project, survey and evaluation of materials, configurations, and thermodynamics and fluid-flow parameters for nuclear rocket engine optimization.

Previously was Task Engineer for NERVA in the coordination and engine-system integration of the SNP-1 contract task, NRX-B; served with reactor review committee in the evaluation of Kiwi B reactors and the coordination and engine-system integration of the WANL NERVA reactor design; also responsible for radiation effects, nuclear safety, and other nuclear aspects of the NERVA development project.

Was the responsible engineer for preliminary and final design on nuclear aspects of Test Cell D (later ETS-1) Project. Also provided consultant services to the E-MAD design specifications and facility design review.

1952 - 1955: Lane Wells Company. Geophysical Engineer. Project Engineer in the development of radioactive tracer techniques for oil well logging. Also supported the engineering development and analysis of neutron and gamma ray logging for oil exploration.

1951 - 1952: Northrop Aircraft Company. Engineer. Radome design and development for SNARK missile navigation radar.

Professional Affiliations

Member - American Nuclear Society

Member - American Institute of Aeronautics and Astronautics

STEPHEN S. BACHARACH - Phase I Project Engineer (backup)-Support

Education

B.S.E.E., Purdue University, 1939
Graduate School, Power Plant Engineering, Purdue University, 1940
George Washington University, Mathematics, 1942
USDA Graduate School, Gas Turbines, 1943

Experience

March 1963 to Present: Aerojet-General Corporation. Mr. Bacharach has provided technical direction and management of design and construction of facilities for development and test of the nuclear rocket. Coordination of radiation effects, health and safety disciplines to assure that the result of their work is properly incorporated in designs. Direction of activities of facility and equipment engineers and consultation on special problems in design and construction. Responsibility for preparation of design criteria, conceptual designs and cost estimates. Planning, scheduling and supervision of the work of subcontractors and architect-engineers to assure compliance with schedules and criteria and maintaining continuous liaison with customer during all these activities.

1951 - 1963: Senior Mechanical Engineer - Nuclear. Consulting and architect-engineering work in nuclear and conventional power plant design and construction. With Burns and Roe, Inc., Combustion Engineering, Inc., and Gibbs and Hill, Inc. Responsible for supervision and direction of mechanical-nuclear engineering and design work on control station power plants and other industrial applications of nuclear energy. Full responsibility for coordinating other engineering disciplines, preparation of plant and system design criteria, conceptual designs, hazards analyses, instrumentation and control, specifications for reactors and reactor auxiliaries, site evaluations, fuel handling and other tasks related to plant design.

Projects included:

Enrico Fermi	- 186,000	ekw PWR - Trino, Italy
BR-3	- 11,500	ekw PWR - Mol, Belgium
SPWR	- 25,000	ekw PWR - USAEC
PM3A	- 1500	ekw Portable Military Reactor for McMurdo Sound, Antarctica
PM-1	- 1,000	ekw Portable Military Reactor, Sundance, Wyoming
Talcher	- 200,000	ekw Fossil-fueled plant, Orissa, India
CANEL	-	Sodium heater, leak monitoring system, instrumentation and control - U.S. Corps of Engineers
Enrico Fermi	-	Reactor Vessel for Fast Breeder Reactor, APDA, Monroe, Michigan
Shippingport	-	Final portions of reactor pressure vessel fabrication and test system design and fabrication.

Licensed Professional Engineer: New York State

Societies

American Nuclear Society: Presently Chairman, Standards Subcommittee
ANS-7, Nuclear Component Criteria (Scope: To identify the need for
and formulate standards for functional and safety criteria for reactor
plant components.

To provide liaison with other technical societies and committees who
provide design, materials, fabrication and maintenance standards that
are applied to nuclear plant components).

National Society of Professional Engineers

California Society of Professional Engineers

D. L. LIMBACHER - Phase II Project Engineer (backup)-Systems Analysis

Education

B.S. - Physics, University of California, 1956
Graduate Study - University of California, Reactor Operator
Training on 75KW AGNIR Reactor at Aerojet-
General Nucleonics

Experience

1962 to Present: Aerojet-General Corporation. Mr. Limbacher's present assignment involves the promotion and coordination of all Nuclear Division I and C departments. As a staff member to the Nuclear Division VP, Mr. Limbacher is involved in all activities concerned with I&C for LMFBR. He was Manager of Instrumentation and Controls Department, Engine Test Stand No. 1, Nuclear Rocket Development Station. He was principally responsible for management of Data Acquisition, Process and Nuclear Controls, Reactor Safety, Closed Circuit Television, Communication, Safety and Warning, Electrical Power Systems Computer Programing, Data Processing. In addition, he was responsible for management of design activity, including technical direction of the Design Contractor for the Instrumentation and Control System for the NERVA Engine Test Facilities. Specified design criteria and requirements for the system design and subsequent design modification, provided design criteria and design review of modifications to the reactor test cell at the Nuclear Rocket Development Station (NRDS).

1960 to 1962: Air Force Propulsion Development Laboratories, Edwards Air Force Base, Branch Chief-Data Systems. Principally responsible for all Data Systems, Controls, Electrical Power, Safety Systems, Data Processing and Reduction, Computer Programming in support of applied research propulsion system testing involving approximately 40 test facilities at the AF propulsion laboratory. Also provided I & C system design for in-house construction of

facilities. Provided direction of design contractors along with design review and criteria for advanced testing facilities. Section Chief - Magnetic Tape Systems and Telemetry Ground Station. Project Engineer - Research and development of Low Level Multiplexer, Liquid Hydrogen Mass Flowmeter, and High Temperature Probe.

1957 - 1960: Rocketdyne-Division of North American Aviation, Area Instrumentation Engineer. In charge of all Instrumentation and Controls for Rocketdyne, Atlas and Thor Engine Test Facilities at Edwards Rocket Laboratory. Participated in initial design of Instrumentation and Controls for the Rocketdyne F-1 engine test stands at Edwards.

1956 - 1957: Convair, Flight Test Instrumentation Engineer. Project Instrumentation Engineer on Flight Test of F-102 aircraft.

Publications

An Instrumentation and Control System for Ground Test of the NERVA Engine. 1965 11th National (20th Annual ISA Conference and Exhibit) ISA Aerospace Instrumentation Symposium.

Chairman - Workshop Session "Systems Noise" - 1964 - 12th National ISA Aerospace Instrumentation Symposium.

Professional Affiliations

Inter Range Instrumentation Group (IRIG) member - Telemetry Working Group, 1962.

Instrument Society of America, member - Standards Committee - Sub-committee 8A-RP 37.3, 1961-1963.

Instrument Society of America, senior member - Aerospace Industries Division - member - Steering Committee, 1967.

Static Test Instrumentation - Rocketry - United States Navy Bureau of Ships - Member - Steering Committee, 1960.

Inter Range Instrumentation Group (IRIG) Associate Member - Transcorder, Sub Group, 1961.

ERNEST R. SITA - Phase II Project Engineer (backup)
Literature Support
- Phase II Group Engineer (backup)
Instrumentation Candidates

Education

B.S. (E.E.), Carnegie Institute of Technology, 1956

Experience

1960 to Present: Aerojet-General Corporation. Mr. Sita is currently responsible for the development of radiation-hardened instruments as part of the instrumentation portion of the NERVA nuclear rocket program. This position encompasses several tasks emphasizing instrumentation and controls component engineering and management concerning development of diagnostic and controls transducers for use in severe nuclear environments. His responsibilities include design of prototype hardware, conductance of nuclear and non-nuclear testing of prototype units, and prepare specifications and drawings of final design for commercial procurement. Additional duties have included preparation of diagnostic and process instrumentation and controls criteria and specification for NERVA test stand facility, coordinated installation and checkout phases of NERVA test facility.

Titan overall engine controls system responsibility for test stand testing complex, and development of a modular plug-in patchboard controls system to provide greater flexibility and utilization of the test complex to handle a wider variety of test programs.

1956 - 1958: Northrop Aircraft Incorporated. As an environmental test engineer Mr. Sita was responsible for the environmental testing of electrical components for the Hawk, Snark, F-89, T-38 and the F-5 weapons and aircraft systems. Mr. Sita prepared criteria and specification and coordinated construction of a GSE environmental test facility.

He was responsible for all electrical aspects of an environmental test laboratory and while in this position was responsible for the:

- Design and installation of a solar radiation facility for use in a vacuum chamber;

- Design and installation of a Ward-Leonard motor control system to provide up to 500 hp output in a vacuum chamber with a variable speed range of 0-9600 rpm;

- Design and installation of the electrical portion of various environmental test facilities such as: 100,000 force-pound electrohydraulic shaker facility and sand and dust wind tunnel.

1951 - 1956: Westinghouse Electric Corporation. Responsible for the calibration and checkout of switchgear components, subassemblies and assemblies.

A. D. WILCOX - Phase I Group Engineer (backup)-Nuclear Analysis

Education

B.S. (Engineering, Physics) South Dakota State University, 1953
M.S. (Physics) South Dakota State University, 1955
Oak Ridge School of Reactor Technology - Graduated 1958

Experience

1964 - Present: Aerojet-General Corporation. Supervisor, Radiation and Shielding Section, Nuclear Analysis Department. Mr. Wilcox is responsible for radiation analysis required for design of NERVA components and for design support of advanced facilities. He is also responsible for NRO reactor analysis as required. Prior accomplishments for which he has been responsible include NERVA propellant heating, nuclear heating analysis of Phoebus-2 nozzle, and FFTF analysis.

1962 - 1964: Ling-Temco-Vought. Nuclear Engineering Specialist. In this capacity, Mr. Wilcox was responsible for reactor kinetics and reactor core analysis in support of the Pluto Nuclear Ramjet Studies. Included in this were accident analysis, control characteristics and reactivity predictions.

1955 - 1962: General Electric Company. Senior Physicist. Mr. Wilcox performed design analysis on reactor control components for the Aircraft Nuclear Propulsion Program.

Professional Affiliations

Registered Professional Engineer since 1959 (Ohio)

Publications

ASME/ALAA/APS Conference on Space Simulation Held in Philadelphia, Pennsylvania, 1967: "Radiation Simulation Problems in NERVA Ground Tests"

A. H. KREEGER - Phase I Group Engineer (backup)--Thermodynamic Analysis

Education

Bachelor of Science Engineering, University of California,
Los Angeles, 1957
Graduate Work - Applied Mathematics, Heat Transfer, Engineering
Management - University of California, Los Angeles
Graduate Work in Radiation Heat Transfer, Applied Mathematics, 1957-1965
University California, Los Angeles short courses in Design of Space
Power Systems and Thermal Control of Spacecraft, 1963-1964

Experience

1960 to Present: Aerojet-General Corporation. Mr. Kreeger is a supervisor of the Heat Exchange Components Group. He is responsible for the design and development of the heat exchangers used in the SNAP-8 Power Conversion System. Heat exchange components include liquid metal recuperators, boilers, radiators and condensers, as well as components using conventional fluids such as water, air and oil.

Primary emphasis currently has been in boiler development where problems with wetting, baffling, flow stratification and stability, and mechanical design have been studied both analytically and experimentally. Development programs were planned, budgeted and completed which required analysis, test hardware, fabrication, test planning and evaluation of results.

Liquid metal heat exchangers have been developed using NaK as both the heated and cooled fluids. Tests were planned and conducted verifying the design analysis. A unique feature of one of the heat exchangers was the requirement to reduce heat transfer effectiveness to protect the containment vessel walls from excessive thermal stresses during transient operation. The solution to this problem required internal baffling and external flow dividers which have been proven during extensive testing.

Previous work in the Power Systems Department included:

1. Thermal analysis of rotating machinery.
2. Design of test loops including mechanical, structural, thermal and hydraulic aspects.
3. Research on rotating seals.
4. Design of corrosion capsule test facilities.
5. Design of space radiators including ground test units with heat rejection to cold walls augmented by internal and forced convection.

1957 - 1960: USAF - Aircraft Maintenance Officer - Maintained liaison between maintenance and supply functions in support of a Medium Bomb Wing.

Publications

Co-author - "Some Aspects of Mercury Boiler Design and Operation," SAE Paper 741-D, 1963.

"Design and Development of the Mercury Boiler for the SNAP-8 System," 1st Annual Specialist Conference on Rankine Space Power Systems, CONF-651026 Reactor Technology.

Co-author - "SNAP-8 - A Technical Assessment," Mechanical Engineer, November 1967.

"Design and Development of the SNAP-8 Multi-Tube Condenser," 1st Annual Specialist Conference on Rankine Space Power Systems, CONF-651026 Reactor Technology.

H. J. SNYDER, JR. - Phase I Group Engineer (backup) - Thermodynamics Analysis

Education

BSME, Massachusetts Institute of Technology, 1951
MS (Nuclear Science), Carnegie Institute of Technology, 1957
Graduate of Oak Ridge School of Reactor Technology, 1957

Experience

1960 - Present: Aerojet-General Nucleonics. Head, Mathematics and Analysis Section. Responsible for stress, thermal, hydraulic, nuclear, shielding and hazards analysis performed in support of projects and programs at San Ramon and for computing and programming. Previously responsible for thermal, hydraulic and nuclear analyses for the Army Gas-Cooled Reactor Systems Program and the Hydrazine Process Development Program. Responsible for planning and evaluation of the test program for the GCRE and ML-1. Project Engineer for the study of a 100 Kwe, fast gas-cooled reactor, Brayton-cycle system for space power application; and a 100 Kwe solid graphite thermoelectric power system for undersea power application.

1956 - 1960: Westinghouse Electric Corporation. Nuclear Engineer. Participated in the startup and operation of the Westinghouse Testing Reactor and the Oak Ridge Research Reactor. Responsible for the complete mechanical design and fabrication of the WTR critical experiment reactor, WTR core structure, and the remote operating handling equipment. Performed thermal, hydraulic, stress, and nuclear analyses, and experiments related to the core of the WTR and subsequent in-reactor experiments.

1953 - 1955: Noble Company. Mechanical Engineer. Project Engineer for the design of special missile handling equipment, overhead and gantry cranes, and special material handling equipment; responsible for the design

and construction of ground facilities for a major missile project, long-range facility planning studies, design of movable support structures for optical tracking equipment, and design of down-range fuel storage facilities.

1951 - 1953: U.S. Air Force. First Lieutenant, Project Engineer, Research and Development Command.

Publications

A. B. Burgess and H. J. Snyder, "MINERVA, A Nuclear Rocket Steady State Systems Analysis Computer Code," AN-1544, December 1966

H. J. Snyder and P. J. BuBois, "MARCO IV Code for the Multichannel Aerothermodynamic Analysis of a Nuclear Rocket Core," AN-1543, December 1966

Professional Affiliations

American Nuclear Society

American Institute of Aeronautics and Astronautics

Nuclear Engineer, State of Pennsylvania

Mechanical Engineer, State of Missouri

Mechanical Engineer, State of California

SUSUMU NAKAZATO - Phase I Group Engineer (backup) - Thermodynamic Analysis

Education

B.S. Ch.E. - Illinois Institute of Technology, 1944
M.S. Ch.E. - University of Michigan, 1947
Chemical Engineering - Illinois Institute of Technology
Applied Mathematics - University of Southern California
Nuclear Engineering - University of California at Los Angeles
Space Exploration - University of California at Berkeley

Experience

1956 to Present: Aerojet-General Corporation, San Ramon. Mr. Nakazato is Manager, SNAP-8 Support Department. He is responsible for all SNAP-8 technology support programs at San Ramon plant, including experimental loop programs to obtain data on material heat transfer and fluid flow problems of a NaK-to-Hg boiler. Directs the design, construction and operation of all alkali metal and mercury components utilized in the San Ramon SNAP-8 boiler development, heat transfer and materials program. Previously, as Manager, Applied Mechanics Department, provided administrative direction for the Alkali Metals evaluation program concerned with the development of high temperature thermophysical properties of lithium, sodium, potassium, rubidium and cesium.

1950 - 1956: Atomics International. Senior Research Engineer responsible for development studies including mass transfer of stainless steel components in alkali metal.

1949 - 1950: Illinois Institute of Technology, Associated Research Engineer.

1946 - 1947: Institute of Gas Technology, Research Assistant.

Publications

"Testing of Electronic Components in a Nuclear Environment," co-author, Journal of Environmental Science, Vol 7, No. 2, April 1964.

"Heat Transfer Investigations of Polyphenyl Coolants," TID 7529, 347-356.

"Organic In-Pile Loop NAA 18," NAA-SP-1592.

"In-Pile Loop Tests of GCRE Elements" IDO-28539, Contributor: Reactor Handbook, Vol. IV, 2nd Edition, Inter-Science Publishers, John Wiley & Sons, 1964.

Professional Affiliations

American Institute of Chemical Engineers

American Institute of Aeronautics and Astronautics

Professional Engineer, State of Illinois

Design Award

Master Design Award, May 1963, for ML-1 Fuel Element Product Engineering.

IRWIN M. REHN - Phase I Group Engineer (backup) - Material Evaluation

Education

B.S., Chemistry, University of Illinois, 1946.
Graduate studies in Engineering and in Physical and Inorganic
Chemistry, General Electric School of Nuclear Engineering,
Richland, Washington, 1949 - 1953.

Experience

1955 to Present: Aerojet-General Corporation. Mr. Rehn recently was responsible for analysis of material problems related to nuclear systems in outer space including both the cryogenic and the high temperature gas environment in the NERVA engine. The problems include the radiation damage effects, thermal stress, low cycle fatigue as well as the test methods for evaluating such problems. Materials involved include stainless steels, nickel base alloys, titanium, refractory metals, and nuclear shield materials. Corrosion evaluation of materials in adverse environments, including liquid metals. He has also worked on the development of refractory composite coatings for rocket nozzles for very high temperature systems and development of new techniques of evaluation of plasma deposited refractory coatings; literature study of liquid metals system for SNAP-8 - preparation of Report 2550, "Bibliography on Liquid Metals Technology of H_g, K, Na and NaK"; evaluation of embrittlement effects of carbon, hydrogen, and nitrogen impurities in liquid metal loops at elevated temperatures for long periods of time; and methods of analysis of low level impurities in liquid metals were investigated.

Mr. Rehn worked on materials development studies for the thermionic converter power generation as well as Cesium liquid and vapor containment and compatibility of ceramic insulators with Cesium vapor and the evaluation of materials compatibility limitation in Cesium atmospheres at very high temperatures for long periods of time; selection of suitable refractory

metals and insulators for nuclear thermionic systems; research and development of materials for liquid lithium cooled reactor systems for power generation in space; physical property evaluations at high temperature, and studies of refractory structural and bearing materials for lithium loops; evaluation of refractory carbide materials and techniques of evaluating performance in operation of pump bearing materials for lithium at 1200° to 1800°F.

Mr. Rehn has worked on the development and analysis of materials for the Gas-Cooled Reactor Experiment and the ML-1 Reactor. Responsible for the fuel element metallurgy and the fabricating and control techniques for the GCRE, he was also involved with the evaluation of corrosion effects in high energy chemically fired rocket engines and pyrophoric titanium problems in oxidizers, and materials selection for fuming nitric acid systems.

1948 - 1955: General Electric. Mr. Rehn worked in reactor technology relative to Uranium Fuel Elements, separation of Pu, U, and fission products from spent fuel elements and evaluation of corrosion problems in radioactive system.

1946 - 1948: ANL. Measurement of thermal conductivity of sodium and NaK at elevated temperatures and evaluation of thermoelectric and galvanic and potentials in liquid sodium and NaK system and the preliminary studies of corrosion in NaK systems in static and dynamic flow systems were Mr. Rehn's duties at ANL.

Affiliations

Member - American Society for Metals

Registered Professional Engineer, State of California

Metallurgical Engineer

G. W. TITUS - Phase I Group Engineer (backup) - Material Evaluation

Education

BScE, Oregon State College, Corvallis, Oregon, 1950

Experience

1956 - 1967: Aerojet-General Corporation. Manager, Technical Services Department. Principal investigator for a program to characterize the high-temperature behavior of nickel alloys in air. This program will investigate the composition and structures of oxide films, chemical changes in the matrix, phases present in the alloys, and creep of the alloys.

Performed materials studies in support of a 10 Kw radioisotope-(Co-60) powered Rankine cycle system. Evaluated compatibility of cobalt and other materials in contact with NaK and each other at elevated temperature. Selected materials to be employed in the heater portion of the system.

Was in charge of materials selection and evaluation for the ML-1, a compact, mobile, gas-cooled reactor. Directed the high temperature fuel irradiation and compatibility program for both the ML-1 and the GCRE-1. Acted as technical director and liaison to an extensive materials testing program at Battelle Memorial Institute. Program included studies of the effects of high temperatures on the mechanical properties of nickel-based alloys and stainless steels.

1953 - 1956: U.S. Steel Corporation, Metallurgist.

Publications

"Long Term Air Corrosion of Several Nickel-Based Alloys", G. W. Titus and J. S. Brunhouse; presented before the Eleventh Annual AEC Corrosion Symposium, Upton, New York, May 23-25, 1962.

"Evaluation of Metal Alloys for Cladding the Fuel Element in a High Temperature Nitrogen Cooled Reactor", G. W. Titus and J. S. Brunhouse; presented at the Annual Meeting of the ANS, Pittsburgh, Pennsylvania, 1961

"Corrosion of Nickel-Based Alloys in a High Temperature Nitrogen Environment", G. W. Titus and J. S. Brunhouse, presented before the Tenth Western Regional Conference of the National Association of Corrosion Engineers, San Francisco, 1960.

Professional Affiliations

American Society of Metals

American Welding Society

C. E. HARTBOWER - Phase I Group Engineer (backup) - Materials Evaluation

Education

B.S. (M.E.) Worcester Polytechnic Institute, 1943

M.S. (M.E.) Worcester Polytechnic Institute, 1958

Experience

1962 to Present: Aerojet-General Corporation. Mr. Hartbower came to Aerojet-General as a research engineering specialist responsible for the extensive fracture toughness research conducted in support of the Second-Stage Minuteman (6Al-4V Titanium) Development Program. He is now responsible for all fracture toughness studies in the Materials Advanced Technology Department. The studies included an evaluation of plane-strain fracture toughness in 18% nickel maraging steel plate for use in the 260-in.-dia. rocket motor case, an investigation of the variation in plane-strain fracture toughness in ring-rolled forgings for Minuteman rocket motor cases, and current research on the mechanisms of slow crack growth using the SWAT detection system. The fracture testing involves a wide variety of specimen testing, including part-through-crack, tensile center-notch, through-crack tensiles, a slow-notched-bend specimen, single-edge notch tensiles, and precrack Charpy slow bend and impact.

1961 - 1962: Manlabs, Inc. Mr. Hartbower was in charge of an Air Force Contract titled "Metallurgical Variables Affecting Fracture Toughness in High-Strength Sheet Alloys."

1943 - 1961: Civilian Naval Engineer. From 1943 to 1945, Mr. Hartbower was employed as a welding engineer at the Naval Gun Factory in Washington, D.C., and as a metallurgist at the Naval Research Laboratory from 1945 to 1952. In

1952, he was transferred to the Watertown Arsenal Laboratory to initiate a program in titanium welding research. He later became chief of the welding section, then chief of the metals joining branch and deputy chief of the materials sciences laboratory of the Watertown Arsenal Laboratories.

Publications

Mr. Hartbower has published more than 40 research papers in the field of welding engineering, welding metallurgy, and mechanical metallurgy.

Professional Affiliations

American Welding Society
The American Society for Metals
The American Society for Testing Materials
Registered Mechanical Engineer in Massachusetts
Metallurgical Engineer in California

Committees

He is a member of several committees, including AWS-ASTM Subcommittee XI - Titanium Filler Metal (Chairman), AWS Technical Papers Committee, AWS Missiles and Rockets Welded Fabrication Committee, WRC Aerospace Advisory Committee, Commission IX of the International Institute of Welding, and the ASTM Fracture Testing Committee (E-24).

W. KOUNTANIS - Phase I Group Engineer (backup) - Radiation Effects

Education

BS (Electronic Engineering), California State Polytechnic College,
San Luis Obispo (1959)

Experience

1966 - Present and 1960 - 1965: Aerojet-General Nucleonics.

Mr. Kountanis is currently responsible for instrumentation and controls on all liquid metal systems. He is also engaged in radiation effects of instruments subjected to nuclear blast.

Previous work at AGN included responsibility for design, development, checkout and operation of the instrumentation and control system for SNAP-8 mercury corrosion loops. Work areas included measurement and control systems for pressure, temperature, flow, and vapor quality. Also included was the design of power distribution and power systems.

Prior projects included participation in the analysis of Electro-Magnetic Pulse (EMP) radiation effects on the minuteman second stage propulsion system, design and checkout of control systems for ML-1 reactor and for instrumentation, and controls on various projects including the Hydrazine Program, several liquid metal loops and plasma physics support. Work on these projects included temperature, pressure, flows and safety system instrumentation and control, vacuum system controls, and power distribution systems design.

1965 - 1966: Kaiser Engineers. As Senior Instrumentation Engineer he was responsible for the instruments and controls design for the LOFT reactor and for Spacecraft Environmental Space Chamber modifications. Work included the design of pressure, temperature, flow and vacuum measurement and control systems. A major contribution was the design of an automatic sample removal system for the LOFT reactor.

1959 - 1960: Douglas Aircraft Corporation, Santa Monica.
Mr. Kountanis contributed to the design of the missile engine control and emergency power system for the THOR missile.

1957 - 1958: K-F Development Company, Redwood City. He worked on the checkout, installation, and maintenance of closed circuit radio systems and supervised their production for the K-F Development Company.

1950 - 1953: U.S. Navy. As an electronic technician he was responsible for repair and maintenance of radio, radar, and sonar equipment.

R. C. ROSSER - Phase I Group Engineer (backup) - Stress, Strain and Vibration

Education

BSCE, Swarthmore College, 1957

MSCE, University of Southern California, 1961

Experience

1964 - Present: Nuclear Rocket Operations, Aerojet-General Corporation. Prepared instrumentation plans and performed all analyses for defining reactor vibrations on the NRX-A2, NRX-A3, NRX/EST, NRX-A5, NRX-A6, CFDTS, XECF, XE-1 and XE-2 reactor tests. This includes component evaluation as well as engine performance. Developed and directed vibration testing of XECF. Presently developing environmental criteria for NERVA engine.

1961 - 1964: Solid Rocket Operations. Responsible for development and application through shock and vibration testing of advanced analytical methods of solutions for complex structural problems.

1957 - 1961: North American Aviation. Structures Engineer performing stress and primary load distribution analyses on air induction system of B-70, F-108 and X-15 aircraft.

L. L. BICKFORD - Phase I Group Engineer (backup) - Stress, Strain and Vibration

Education

BSEE, California State Polytechnic College, 1958
MSE, UCLA, 1963

Experience

1963 - Present: Aerojet-General Corporation. Mr. Bickford is responsible for the analysis of all operational control systems used in both liquid and solid propellant rocket engines. His organization is also responsible for the analysis of feed system coupled combustion instability (chugging) and vehicle-coupled longitudinal instability (Pogo). Recently, Mr. Bickford was project engineer for the Pogo analysis of the Saturn propulsion system, which was conducted for NASA-MSFC.

Mr. Bickford was responsible for stability and control analysis of the transtage hydraulic gimbal test actuator and for establishing a complete analytical model of the Titan II longitudinal oscillation "Pogo" problem involving dynamics of the tankage, hydraulic lines, pumps, combustion process, and elastic airframe. In addition, he established the complete analytical model of the Apollo engine and feed system which was used to diagnose and eliminate a low frequency combustion instability problem.

1959 - 1963: General Dynamics, Pomona. Mr. Bickford was a senior dynamics engineer. He participated in the design of linear autopilots and had lead engineer responsibility for the nonlinear adaptive autopilots associated with the Tartar and Terrier class of flexible missiles.

1958 - 1959: Westinghouse Electric Corporation, Bettis Atomic Power Division, Pittsburgh, Pennsylvania. Mr. Bickford conducted nuclear reactor hazard studies on the analog computer with respect to control system malfunction.

Affiliation

Registered Electrical Engineer, State of California

D. S. DUNCAN - Phase I Group Engineer (backup) - Safety Analysis

Education

B.S., Engineering Physics - University of California, 1953
Graduate Studies, Nuclear Engineering and Mathematics -
University of California, 1956 - 1958

Experience

1962 - Present: Aerojet-General Corporation. In his present position Mr. Duncan is responsible for safety evaluation of the engine test program including evaluation of both the test article design and all systems which comprise the Engine Test Stand Complex (ETS-1) at Nevada. ETS-1 is the facility which will be utilized for the first full-scale tests of the NERVA engine in 1968. Mr. Duncan is also a member of the engine design team and recently was responsible for coordinating the preparation of the XE Safety Analysis Report. In addition to his activities in the X Engine Development Program, Mr. Duncan is actively participating in the design of E/STS 2-3 which is being designed for testing the large NERVA engine, and in the safety evaluation and review of the reactor development tests which are currently being conducted at the Nevada test site. Prior to the major program reorientation and the deletion of the Reactor-In-Flight Test (RIFT) Program in January 1964, Mr. Duncan was responsible for the technical direction, coordination and integration of all flight safety evaluations and experimental programs performed under Contract SNP-1 in support of the NERVA Engine Development Program.

1956 - 1962: Atomics International, North American Aviation, Incorporated. Project Engineer on the Piqua Nuclear Power Facility (PNPF) Operations Analysis Program. As Project Manager, his specific responsibilities were to assist the AEC in demonstrating the safe operability and economics of the Piqua Plant, to acquire and analyze technical data which could be utilized to improve future

plant design, to evaluate the performance and lifetime of the system components and fuel, and to continuously evaluate all aspects of plant safety. Prior to this assignment, Mr. Duncan was responsible for hazards analysis, coolant activation studies, shielding analyses and design, fuel-element fouling and film formation studies, and development of new methods and techniques for deep neutron penetration calculations and shield optimization. In this regard Mr. Duncan was associated with a wide variety of nuclear reactors including the Hallam Nuclear Power Facility, SRE, PNPf, OMRE, SNAP-4 and 8, and the AI Research and Laboratory Reactors.

Publications

Has authored numerous AI and AGC reports on hazards analysis, radiation shielding, calculational techniques and computer programs and has presented several papers to the American Nuclear Society.

Professional Affiliations

Member of American Nuclear Society

R. K. STEELE - Phase II Group Engineer (backup) - System Applicability

Education

B.S. (Petroleum Engineering) University of Pittsburgh, 1941
M.S. (Structural Engineering) University of Florida, 1949

Experience

1959 - Present: Aerojet-General Corporation. Mr. Steele joined Aerojet-General as a Technical Specialist charged with the responsibility for establishment and operation of the Structural Test Laboratory to conduct tests on research, development and production items. In this capacity, he was responsible for the planning, supervision, and development of tests and equipment to improve and evaluate designs, materials, and manufacturing methods and processes for rockets and rocket components.

Mr. Steele currently is head of the Special Projects section. This group has developed items ranging from infrared ovens for brazing brass pipe joints in submarines, to thirty-inch diameter cells for measuring static and dynamic soil stresses in earth fills. Several research contracts have been obtained for development of a system to prevent catastrophic failure of pressure vessels by analyzing the stress waves emitted by a growing flaw.

1957 - 1959: Temco Aircraft Corporation. During this period Mr. Steele was director and Head of the Hydraulics and Propulsion Laboratory.

1954 - 1957: General Electric Aircraft Nuclear Propulsion. As head of the Major Components Development Department, Mr. Steele was responsible for the operation of Propulsion Unit Test Cells. This involved structural and performance evaluation of nuclear engine components in the Gas Dynamics Facility capable of experimental stress analysis combined with hot flow testing. He was responsible for the requirements and design of special test equipment for

use in the Gas Dynamics Laboratory and also supervised the Structures Laboratory engaged in experimental stress evaluation of shields, reactor components and core configurations.

1949 - 1954: U.S. Naval Structural Research and Evaluation Laboratory. During the interval, Mr. Steele was a Divisional Director of the Structures Laboratory where he planned, staffed, organized, activated, and operated the Structures Division on research projects associated with BuDocks world-wide operations.

1949 - 1947: Associate Professor, University of Florida. During this period Mr. Steele taught courses in structures.

1947 - 1941: (Curtiss Wright Corporation) as Senior Resident Engineer he was engaged in stress analysis, design, test, and structural research of Naval aircraft and missiles. This involved development of laboratory testing, detailed loads delineation and stress analysis of aircraft and their components.

Publications

Mr. Steel has many publications on systems testing including SWAT systems.

Professional Affiliations

American Men of Science

Society for Experimental Stress Analysis

Committee 323, Prestress Concrete Research Committee

RODNEY HOFF -- Phase II Group Engineer (backup) - Instrumentation

Education

B.A. (Math), Washington State College, plus 1 year graduate electrical engineering, 1945
General Electric School of Nuclear Engineering, Richland, Washington;
Graduate courses in Advanced Electronics, Theoretical Physics, Atomic Physics, and Nuclear Reactor Theory
UCLA Night School Extension; Graduate courses in Nuclear Engineering, Servomechanisms, Nuclear Reactor Control, and Transistor Fundamentals
Sacramento State College and UC Davis Extension: Advanced Engineering Mathematics, Computer Programming, and Dynamic System Analysis

Experience

1963 - Present: Aerojet-General Corporation. Mr. Hoff is the responsible engineer for all temperature measurements on the NERVA Project. These temperatures range from cryogenic to 4500°R in an intense nuclear radiation environment.

1955 - 1963: Atomics International (Also October 1952 to February 1955). Mr. Hoff's assignments included SNAP-2 Reactor Temperature Control. Previously he did developmental work in Thermionic and Thermocouple Energy Conversion. For about 4 years he was responsible engineer in charge of reactor safety and control for the Advanced Sodium Graphite Reactor Program. Still earlier, he worked on automatic safety shutdown devices for insertion in nuclear reactors.

February 1955 - September 1955: Redel, Incorporated. Mr. Hoff headed the Instrument Department where he devised, purchased, and maintained instrumentation for developing a hyper-velocity gun that used spark-ignited hydrazine nitrate propellant.

1946 - 1952: General Electric Hanford Works. Developed or co-developed reactor temperature mapping and punch card recording systems, a liquid level indicator, a metal detector, a weld sorter, portable radiation survey instruments

and the Safety Controller used on the Hanford Reactors for many years. He was also a troubleshooter during various emergencies.

Publications

"The Mercury Jet Switch," Instruments, Vol. 26, p. 1538-41, October 1953.

"REON Hot Gas Thermometry," written jointly with W. P. Gilles and T. F. McGrath, paper No. 35, High-Temperature Thermometry Seminar, Washington, D.C., February 24-26, 1965, published as WASH-1067.

Patents

Patent No. 2,987,455 "Method and Apparatus for Reactor Safety Control" issued jointly with N. E. Huston and C. W. Wheelock.

Patent No. 3,273,048 "Thermionic Diode Converter System," issued jointly with Eugene V. Clark, Jr., and Charles C. Weeks.

D. E. SWARTZ - Phase II Group Engineer (Backup) - Instrumentation

Education

B.A. (Nuclear Physics and Mathematics) Carleton College, 1950
Graduate studies in physics at Drexel Institute of Technology,
Philadelphia, Pennsylvania, 1952 - 1953
Graduate studies in mathematics at Sacramento State College,
Sacramento, California, 1964 - 1966

Experience

1958 - Present: Aerojet-General Corporation. Mr. Swartz is the Supervisor of Applications Section of Instrumentation Department. He is responsible for measurement engineering for NERVA engine testing. The duties include long range planning of measurement system needs, coordination of requirements of data users, analysis and selection of measurement system components, review of installation design, review of component development progress, interface coordination with facility and engine control systems, and review of and reporting on test results. Measurement criteria and design specifications are prepared to cover all aspects of measurement engineering for new programs. Long range program needs are anticipated and guidance is given to development groups in initiating programs to satisfy the projected needs. Special measurement problems are analyzed and specialized components and circuits are designed and procured.

Past activities included planning and analysis associated with nuclear effects testing of instrumentation components. Special radiation effects and circuit application analysis.

Mr. Swartz was also responsible for establishing and maintaining a centralized transducer and calibration facility. Duties included supervision of laboratory personnel, establishing calibration techniques and procedures,

coordination of calibration services provided by other divisions, development and procurement of specialized transducers, establishing and maintaining inventory needs, routine support of the operating groups, and design of calibration equipment.

1955 - 1958: Douglas Aircraft Company. Mr. Swartz was a Flight Test Engineer group leader responsible for instrumentation system design, procurement, installation and functional checkout of all test instrumentation on experimental F5D naval aircraft and on A4D aircraft used in conjunction with nuclear weapons testing at the Nevada Test Site.

1952 - 1955: Naval Aircraft Factory, Naval Air Materiel Center. At NAF Mr. Swartz was a Test Officer performing work functions on all phases of instrumentation for Research and Development, shipboard installation and qualification of aircraft and missile catapults and arresting gear. He was responsible for instrumentation system design, procurement, installation, operation, and data reduction.

S. DAIRIKI - Phase II Group Engineer (backup) - Systems Acquisition

Education

B.S. (Mathematics) Sacramento State College, 1950

Experience

1953 to Present: Aerojet-General Corporation. Presently assigned to Systems Analysis Section of Nuclear Rocket Operations in the analyses of test data using statistical methods for the NERVA program. Prior to NERVA assignment, Mr. Daiрики worked in the Reliability Section of Polaris Quality Control, doing data processing for manufacturing data and time spans using an electronic computer program. Experience includes applied statistics and reliability using various phases of statistics and mathematics. Statistical methods used are control charts, t-tests, F-tests, analysis of variance, Bartlett's test for homogeneity of variances, regression analysis, and tolerance limits.

STEPHEN A MALMSTROM - Phase II Group Engineer (backup) - Development

Education

B.S.E.E. - Electronics, Heald Engineering College, San Francisco
California (1962)

Experience

1963 - Present: Aerojet-General Corporation, Electronic Engineer.
For the EBR-II program, a breeder reactor fuel production program, designed sophisticated measuring and inspecting circuits used in both the production and quality control phases of the program. Among the instruments designed are 1) a pulsed eddy-current nondestructive inspection system which detects flaws in thin wall tubing, and 2) a volume classification and diameter inspection system used in the fuel pin processing phase.

Participated in the analysis of and co-authored a nuclear weapons vulnerability evaluation of the W71/D12 system. The study was concerned with radiation effects on integrated circuits and solid state discrete components.

As a circuit design engineer, designed and modified support equipment and prototype instruments which vary widely in both physical and environmental characteristics. Among these instruments are 1) a pulser to trigger a 250 kilojoule capacitor bank, 2) an overload detection circuit to protect a 600 KV accelerator power supply, 3) a binary 10 line decoder with memory and output drivers (now a product of Aerometrics), 4) a period circuit for use in the Aerojet-General Nuclear Industrial Reactor, 5) support equipment associated with an X-ray spectrometer system, and 6) high precision instrumentation used to determine the vapor viscosity of liquid metal as well as the control instrumentation for the entire process. Writes, and has published for customer approval, conceptual system designs and proposals. Supervises drafting, fabrication, testing and installation of such designs.

Designed and modified support equipment and prototype instruments for the Mobile Power Plant (ML-1) of the Army Gas-Cooled Reactor Systems Program. Analyzed and modified servo control systems for ML-1. Designed and fabricated a small analog computer for startup and control of the ML-1 gas-cooled reactor. Circuits designed were primarily analog types to monitor and control such parameters as temperature, pressure, radiation field, etc.

As system engineer, designed and developed electrical and electronic equipment required for the specific heat experiments of the Liquid Metals Program. The apparatus consisted of a heating system, a high precision temperature control system, and a temperature measuring system necessary to determine the specific heat of liquid metals at high temperatures.

Designed and developed the electrical and electronic equipment required for testing and fabrication of a fissiochemical loop designed for fission fragment irradiation of liquid ammonia. Designed a system to monitor hydrogen, a by-product of the above experiment.

1962: Heald Engineering College, San Francisco, California, Instructor. At Heald Engineering College instructed mathematic classes in differential and integral calculus.

1962: Nuclear Research Instruments, Berkeley, California, Electronic Engineer (part-time employment). At Nuclear Research Instruments, checked and corrected servo systems and transistor logic systems for the dual-scope-measuring-projector.

D. G. KNEELAND - Phase II Group Engineer (backup) - Inspection Methods

Education

B.S. (Electrical Engineering) University of Connecticut, 1957

Experience

1962 - Present: Aerojet-General Corporation. Mr. Kneeland's work has been concentrated on problems associated with making measurements of various nuclear rocket engine parameters during tests. Initial assignments dealt with the evaluation of transducer designs from materials and operating principal standpoints in order to eliminate those which were incompatible with the predicted test environments. In some cases it was possible to arrange for modifications (through the manufacturers) to increase the probability of success with particular transducers. As the NERVA program progressed, his duties became more involved with the environmental testing of promising candidate transducers and the evaluation of test results. In most cases, test results were discussed with transducer manufacturers to aid in the design of second generation candidates. During these phases of the program his time was devoted to pressure, temperature, and vibration transducers.

Early in 1964 he was assigned sole responsibility for development of a vibration measurement system for use during "hot" engine firings. The scope of work was thereby broadened from development of a transducer capable of surviving and operating in the predicted environments to development of a system to secure diagnostic data for engine performance analyses. The system which evolved consisted of a piezoelectric accelerometer, a radiation tolerant tri-axial cable, and a remotely located charge amplifier. This system demonstrated its workability during "hot" tests in March and April of 1965 and is still being used on currently scheduled tests.

In the fall of 1965 he was reassigned to a new group which was set up, primarily, to provide technical assurance that each measurement system employed during an engine test would meet the requirements of the data requester. This was accomplished by conducting an analysis of each system to determine the effects of predicted environments on cables and transducers and the resultant measurement uncertainties. These uncertainties are then combined with the data recording system uncertainties to obtain a system measurement error band. System modifications are recommended if the error band does not meet the uncertainty criteria established by the data requester.

In addition to the above work, in the fall of 1966 he was assigned responsibility for development of a computer program capable of accepting as input all data concerning transducer calibration uncertainties, environmental uncertainties, and data system uncertainties for all types of transducers used on an engine test, and producing outputs in graphical form depicting measurement uncertainties (in engineering units) for all points within each measurement range. This program has been written for an IBM 360 system and has been checked with numerous trial cases.

1967: Pratt and Whitney Aircraft. For a short time Mr. Kneeland was a senior experimental engineer at Pratt and Whitney where his responsibilities included the design and fabrication of instrument systems for various tests connected with development of a reactor for the SNAP 50 project. Specifically, the tests dealt with liquid metal heat exchangers, liquid metal bearings, and reactor control mechanisms.

1958 - 1962: Combustion Engineering Naval Reactors Division. Mr. Kneeland was involved in preliminary design of reactor plant and secondary system simulators employing operational amplifiers, fhp motors, magnetic clutches, etc. He was required to carry out the test program of all instruments and controls used in the support systems for SLC reactor. When he left Combustion Engineering he was supervisor of the Instrumentation and Calibration Lab. The lab was responsible for instrumenting special tests and for recommending and procuring needed instrumentation.

Professional Affiliations

AIEE and Eta Kappa Nu

[(7)e] 3. Project Plan

The Project Plan that Aerojet suggests is illustrated in Figure 20. A final plan can be evolved during discussions of the work scope a short time prior to the commencement of work. Such details might include the discussion of start time of the second half of the second phase, namely, Conceptual Design of a NDT system. Since Phase I concludes with areas requiring inspection, parameters to be monitored, and the basis for when to monitor, the system concept can be evolved even as the literature search is progressing. The exact nature of the system will have to await the instruments selected, or to be developed, and the modes of inspection. However, much can be done at an early stage, if PNL so wishes it, because data analysis, reduction, and display to some extent are independent of final literature and development requirements.

a. Discussion of Work Scope

A discussion of the scope of effort needed to provide PNL eventually with a working system was discussed in general in the Introduction, Section B, Analytical and Applications Discussion. Aerojet General Corporation believes that these efforts are needed in thoroughly performing the present study.

(1) Specific Analysis, Phase I

Specifically, analysis in Phase I will include but not be limited to the following:

. Core, vessel, piping and component system analysis delineating weak points, connection difficulties, and restrictions based on fabrication limits and quality assurance.

Figure 20 - Project Plan

. Steady state (design and part-load) and transient environmental operating parameters--i.e., sodium temperatures and pressures, coolant-flow rates, cyclic conditions (ramp, step, scram, and normal start-up and shutdown). This will include analysis of flow and mechanical instability.

. Neutronics data, including neutron and gamma radiation spectrum and energy as a function of distance from the core center. Radiation effects on materials will also be included. This material investigation also considers other environmental effects and will make predictions to mode and time of failure.

. Component life and susceptibility to failure based on loads imposed steadily, dynamically, and as a result of temperature, flow, vibration, radiation, or corrosion.

. Abnormal conditions pertaining to safety, including such factors as seismic loads, fission-product release, and Design-Basic Accident. A complete mode of failure analysis will be completed.

. Relationships with other external plant equipment and systems--e.g., core-component handling equipment, vessel accessibility, and ancillary coolant availability.

(2) Analytical Methods, Phase I

The analytical methods and computer codes now employed for determining loadings and performing the detailed stress analyses for current primary loop systems will be utilized. All pertinent analyses (hand calculations through complex computer codes) for full- and part-load, steady state and transient conditions involved in the design will be considered. These will include (but not necessarily be limited to):

- . Calculating temperature distribution and resulting thermal stresses in structural members as a function of:

- (a) Steady-state and transient thermal environment, including the effects of geometry; physical properties of materials; boundary conditions, and the heat-transfer mechanisms of conduction, convection, and radiation.

- (b) Internal heat generation by radiation attenuation. The heat generated will be related to the structural material and geometry, and to the radiation spectra and its energy level.

- . Analysis of fatigue of structural members caused by vibration due to hydraulic and mechanical effects.

- . Analysis of structural members predicting maximum stress, deflection, and/or distortion due to combined thermal and mechanical loads.

- . Limitations of the above items by effects on materials properties of the following: radiation, sodium environment, fabrication processes, operation in the creep range; and instability of heavily loaded thin-walled members.

Additional support activities will consist of the following:

- . A failure-mode analysis of the designs will be made, based on performance history wherever possible. The analysis will include: assessing potential causes of failure; critical areas of plant

performance and safety; effects of operating environment, materials, fabrication, and inspection history; potential for detection of impending and/or actual failure; and accessibility for maintenance and/or replacement.

. Requirements for on-line monitoring systems can then be specified. These requirements will be supported by adequate criteria for physical restraints, operating environments, material and physical description of the component to be inspected, and specification of variables to be measured (either causative or after-the-fact) that will signal the failure.

. For periodic inspections, the applicability of different non-destructive test methods and procedures as applied to each critical area will be defined. Methods may include the conventional techniques of visual inspection (internal and/or external) of surface flaws--enhanced where applicable by magnetic-particle or dye-penetrant techniques; detection of internal flaws by radiography or ultrasonic inspection; detecting excessive deformation by measuring strain or physical dimensions; and destructive testing of samples exposed to identical environmental operating conditions (under the same loading) as the area in question. In addition, such advanced techniques as mechanical-signature analysis to detect initiation of system changes will be considered.

. Criteria of acceptability, based on the sensitivity of the systems will be determined. Schedules and degree of inspection (i.e., internal versus external, partial versus total area, etc.) will be established for each critical area. Procedures for inspecting and evaluating the results (statistical error or replication procedures) will also be prepared.

(3) Literature Search, Phase IIA

During the Phase II portion of the study, in addition to the literature search of instrumentation availability and development of those not available, inspection methods will be evaluated.

Although it is more difficult at the present state of technology to hypothesize on the merits of other nondestructive examinations, it appears to be prudent to continue to examine new approaches for feasibility. This study will continue not only looking for those systems that primarily monitor fault initiation and growth but also those which deal with the change of physical and mechanical properties.

It may be hypothesized as a possible future development that under some conditions an approach to a critical failure condition could be attained over a rather short time. In this event it will be necessary to perform examinations more frequently than would be afforded by periodic postoperational inspections. Such examinations will require greater frequency of inspection and subjection to operating rather than shutdown environments. Operation under such conditions places paramount interest in the following problems: maintainability, safety, and reliability, with assurance of noninterference with reactor system instrumentation and controls and resistance to the radiation, temperature, etc. associated with the environment. These areas will be reviewed.

(4) Conceptual Design, Phase IIB

In addition to the survey of existing instrumentation methods, instrumentation availability, and monitoring methods to be conducted, a major portion of Phase II will deal with the conceptual design of the proposed NDT system and program including development recommendations. This

portion of Phase II (called Phase IIB) will be approached and produce the following results:

Systems designs must consider transducers, transmission of signal, signal conditioning and analysis, parameter display, and possibly process control.

Various approaches to portions of the total system design can be considered independently. For instance, at an early time in the program, consideration and selection of parameter display methods can be completed.

Upon establishment, through the analytical studies, of those portions of the reactor system which require surveillance and in-service inspection the parameters to be monitored, location of measurement, and continuous or periodic frequency of monitoring the system development process can proceed independently. The survey of existing instruments and equipment for specific parameters will establish the optional techniques for further system development. This basic building block approach to system design will assure compatibility of measured parameters with the in-service inspection requirements. The system so designed will be conceptually reported, including detailed description of any required development areas.

b. Discussion of Schedule

As noted from Figure 20, the plan coincides with the discussions in Section IV,A,1 concerning the coordination of the technical analysis, and the project responsibilities and authorities.

Mileposts which can consist of reports and presentations are indicated. The literature search activities of Phase II can commence smoothly since some participants in this phase had been participating in Phase I as consultants or group engineers.

Aerojet believes that this schedule is in logical sequential order and can produce the best results at the earliest possible date.

[(7)e]

B. PLAN, SCHEDULE, AND CONTROL

The importance, technical complexity, and cost of a FFTF surveillance system demands the implementation and use of the most effective means of program management and controls as are feasible. While it is true that the project managers themselves hold the key to successful conduct of a team effort, it is also true that the abilities of these managers to carry out their responsibilities successfully can be greatly enhanced by the proper application and use of some of the formal management tools, techniques, and disciplines. When applied to a particular organization, these formal tools and techniques might be collectively referred to as a management information system. It is the purpose of this section of the proposal to present a general concept of the management information system to be used by AGC, if awarded the Surveillance Instrumentation Requirement Studies contract. Also, the manner in which our management would use such a system and the responsibilities for operating the system are discussed.

1. General Concept

Aerojet-General considers complete and up-to-date planning on all aspects of an operation as necessary for management in order to be able to know what progress is being made, what problems exist, and what management actions must be taken to correct any problems. Complete planning in an undertaking such as the one being proposed on herein must set forth the following:

- a. Objective(s) to be accomplished
- b. Description of work
- c. Schedule, including major phases and milestones
- d. Resources required (financial plus others)
- e. Assignment of responsibilities
- f. Interrelations of work (internal and external)
- g. Method of analyzing progress and adjusting future plans

The elements of complete planning listed above will be applied at various levels within the organization, depending upon the degree of detail that is required.

We will strongly emphasize the planning function as outlined above. In addition to its use internally within Aerojet, the planning function will support the management requirements of Battelle and the AEC with respect to the preparation and submission of annual proposed budgets, work statements, plans, estimates-to-complete, and other such information as may be required.

The existing planning and management information systems (including program evaluation) in use by our operations, NRO will be extended to suit the special needs of Battelle and the AEC. The major components of these systems, as might be applied to the Surveillance Study contract are:

a. Standardized Reporting System

- (1) Financial plans and status
- (2) Schedules and status
- (3) Technical (or performance) goals and status
- (4) Problems and trends
- (5) Action being taken or proposed to correct problems or trends

b. Independent Program Evaluation

- (1) Organizationally independent of operating groups
- (2) Analysis by specialized staff

c. Management Center

- (1) Centralized display of plans and status
- (2) Location for various management reviews and meetings

d. Weekly Management Review in Management Center

- (1) Independent program evaluation, weekly
- (2) Presentations by key personnel, weekly
- (3) Detailed financial presentation, monthly
- (4) Selected presentation by staff groups, monthly
- (5) Each of the above presentations emphasizes:
 - (a) Overall status
 - (b) Actual accomplishments versus plans
 - (c) Problem areas
 - (d) Significant trends
 - (e) Impact of problems and trends on other parts of the total effort
 - (f) Actual or proposed actions to correct problems or bad trends

e. Special Management Tools (as applicable)

- (1) Critical Path Method (CPM) and/or PERT
- (2) Line-of-Balance
- (3) Special programs for financial reports

2. Management Information System Components

Each of the components in Section IV.B.1 of the proposed management information system is discussed in more detail in the following paragraphs.

a. Standardized Reporting System

The purpose of the standardized reporting system is to provide a means of displaying the latest plans and status of work in a summarized form on standard formats. The reporting system will cover financial, schedule and technical (or performance) areas and will also provide summary information on significant problems and trends and the action being taken regarding same. This reporting system will be applied at several levels of management, depending upon the degree of detail needed for the management and control of any particular area of the operations. It is considered premature in this proposal to specify particular formats; however, it is most likely that the standard formats for summarizing the plans and status on schedules and technical (or performance) goals will be identical to those used internally at Battelle on the FFTF Project. The milestone goals and milestones are under the responsibility of the manager at that level. Subordinate levels would similarly have milestone charts corresponding to those levels. During the annual planning cycle, specific milestones and goals would be established for the succeeding fiscal year. With regard to financial plans and status, the charts would show, for any particular level of management or area of effort, the budget for the fiscal year or for the duration of the project, and the actual dollars incurred or committed. These data would be shown in cumulative graphical form, backed up by numerical data showing the budget, actuals, and variances from the budget both incrementally by month and cumulatively to the current date. These financial charts would be prepared and maintained for the same levels and areas of management as for the milestone charts. Thus, throughout a project's total effort, there would exist summaries of complete planning at several levels of responsibility.

In addition to the above formats, the standardized reporting system would also include formats for the summarization of current problems and trends, and the action being taken or proposed by responsible levels of management to correct such problems or trends. All of these reports

would be submitted by the lower levels of management to the higher levels of management on a periodic and frequent basis, not less frequent than each two weeks and possibly as frequent as once a week. The procedures for the preparation and submission of these data would be arranged so as to minimize the administrative and paper workload generated thereby on line managers.

b. Independent Program Evaluation

By independent evaluation is meant an objective assessment of the current status of the Aerojet effort on the Surveillance Study, or any part of it, by comparing actual progress and performance with approved plans, such assessment being moderated by other known facts or problems which may have current or future constraints on the area being evaluated. The accent here is on the independent aspect of the analysis to be performed. This independence is considered desirable in order for the function to be carried out objectively and without regard to where problems may lie. This function would be performed by an existing staff group located within the Administration Department of the Nuclear Rocket Operations in Sacramento. This group would also have additional duties and responsibilities, such as the maintenance and operation of the management center, the preparation and updating of wall charts in the management center, the preparation and distribution of the standardized reports based on rough draft reports prepared by the operating managers, and the preparation of certain progress and status reports required by higher authority.

c. Management Center

This is a specially designed and outfitted room for the purpose of providing a centralized location for the display of current plans and status on all aspects of the project. The management center also serves as the meeting place for various types of meetings, presentations or briefings in which project plans, status, problems and proposed action are to be discussed. The existing NRO Management Center would be used for the Surveillance Study.

d. Weekly Management Review in Management Center

At a regular time each week, a review of the entire effort will be conducted in the management center. The general format of this meeting will be that of a presentation or briefing to senior management by selected speakers. The Manager of Program Evaluation will "M.C." this meeting and will also make the first presentation. This first presentation will be a summary of the weekly overall project evaluation prepared during the previous week. Following the overall evaluation, selected line and staff managers will make more detailed presentations on the status, problems, and proposed actions within their own areas of responsibility. Some of these speakers will be scheduled on a regular basis, others on a special basis. In addition, there will be a special presentation by the Financial Manager once a month to discuss the latest financial trends.

e. Special Management Tools

Aerojet is well experienced in the application and use of the various network planning, scheduling and evaluation techniques such as the Critical Path Method and PERT. These tools will be applied wherever appropriate, and will be coordinated with overall FFTF planning. The Line-of-Balance technique for the scheduler control of repetitive type operations will be used if appropriate. In the financial areas, computer programs already in use by Aerojet on the NERVA program will be used for the narration of budgets and reports of actual expenditures versus budgets variance reports, float reports and so forth as may be required.

It is our intention to carry out complete planning in all areas of its effort, to maintain such planning on a regular basis, and to review actual accomplishments and progress in relation to such plans on a weekly basis. In these weekly reviews by management, emphasis will be placed on the earliest possible detection of problems with respect to schedules,

costs, and technical (or performance) goals and the causes and effects of such problems and trends. Also, particular emphasis will be placed on timely decisions by management with regard to the action required to correct these problems or trends. The system proposed herein is modeled in general after the management systems and techniques developed and so successfully employed by the government during the last ten years in the management of a number of the large high priority programs such as Polaris, Minuteman, Titan and the various space programs. This system, when implemented, will also enable Aerojet to be completely responsive to the needs of Battelle and the AEC for any management data that may be required and will enable Aerojet to maintain and provide the close coordination and liaison on schedules with Battelle, the AEC and its other contractors who will be participating in the FFTF Project.

C. ESTIMATED COSTS AND OTHER FACTORS

1. Estimated Costs

Aerojets' estimated costs are based on a level-of-effort for a cost plus fixed fee program:

Phase I	\$ 41,000
Phase II, Part A - 18 Man-Months	\$ 58,000
Phase II, Part B - 65 Man-Months	\$206,000

Upon definition of a detailed program plan, a detailed cost estimate will be forwarded.

a. Cost Element Discussion

(1) Direct Labor

Aerojet-General Corporation computes direct labor cost for proposals by using wage rate averages for those departments, sections, or organizational pools which will be involved in the performance of the work. For Nuclear Rocket Operations departments, the last three-month moving average rate for each organization involved, adjusted by a percentage factor to provide for increase due to merit, promotion, and cost-of-living considerations would be used by the local AFPRO for proposal purposes.

(2) Direct Labor Overhead, Material Burden, and General and Administrative Expense

Overhead expense for these burden centers is projected on the basis of an evaluation of contract backlog with a reasonable estimate for new awards. These data are related to manpower and material requirements for which the indirect support costs or overhead costs can be estimated. This

estimate is based on statistical data maintained for this purpose which relates indirect expenses to direct contract work. The resulting overhead dollars and rates were negotiated and approved by the local AFPRO in a letter, dated 14 December 1967, covering the subject of Negotiation of FY 68 Overhead Bidding Rates - Aerojet-General Corporation, Sacramento, California. At this time, there is a contemplated realignment of the overhead rates which is not anticipated to increase the cost of the contract.

b. Other Contract Factors

(1) Initiation of Work

Should it be considered expedient, work can be initiated on the proposed program on the basis of a teletype notice of award, letter of intent or other interim contractual authority to proceed.

(2) Validity

This proposal is valid for 60 days from the date of 1 May 1968, after which time Aerojet reserves the right to review for currency and applicability.

(3) Negotiation

Any negotiation pertaining to this procurement should be conducted through Mr. G. L. Ryland, Manager, Contract and Program Administration, Nuclear Rocket Operations, Nuclear Division, Aerojet-General Corporation, Post Office Box 15847, Sacramento, California 95813, Telephone Area Code 916, 355-6063.

(4) Terms and Conditions

This proposal assumes that any resulting contractual authorization would be provided under the terms of the basic ordering agreement negotiated between Battelle-Northwest and Aerojet.

[(2)e] 2. Project Location

The proposed FFTF Study will be conducted by agencies of the Nuclear Division of Aerojet-General Corporation, directed by Nuclear Rocket Operations, at the Sacramento Facility. A "not-to-scale" and "not-inclusive" map, Figure 21, indicates the important sites of this 23,000 acre facility. The analysis groups are housed in Buildings 2019, 2015, and 2025, while the large computer facilities and laboratories discussed in Section C.4 are housed in Buildings 2001, 2002, and 2004. The work conducted at the Sacramento Plant location will be supplemental by efforts of other Aerojet facilities as required to ensure an integrated Nuclear Division team approach to the study effort. This team approach will be manifested through a projectized Phase I effort with all analysis conducted in one area of 2019 by all responsible group members.

[(3)] 3. Workload

The volume of Aerojet-General Corporation workload in general for fiscal years 1965, 66, 67, and predicted for 1968, has been well over the \$400 million level. Specifically, it appears that the engineering and management manpower that would be assigned to the present program is currently, and immediately available at Aerojet. The analysis and development engineers who will be assigned all have the technical skills necessary to accomplish the analysis, and evaluation efforts associated with the program. These personnel can be assigned without conflicting with existing programs.

1 CREDIT UNION	14 HEAT TREAT
2 LRO MANUFACTURING, BLDG 2009
(AIR FORCE PLANT 70)	15 RECEIVING, BLDG 2022
3 LRO MANUFACTURING, ADMINISTRATION
BLDG 2003	16 EMPLOYEES' RECREATION CENTER,
BLDG 2201
4 EMPLOYEES' STORE, BLDG 2014	17 RECREATION AREA
5 CAFETERIA, BLDG 2006	18 GARAGE, BLDG 0002
6 SRO, LRO ENGINEERING, BLDG 2015, 2025	19 AETRON, BLDG 0011
7 SERVICE STATION	20 PLANT ENGINEERING, BLDG 0001
8 MAIN ENTRANCE - GATE 3, BLDG 2020	21 STORAGE AREA
9 ADMINISTRATION & ENGINEERING, BLDG 2001	22 HIGH ENERGY FUEL PLANT
10 NRO ADMINISTRATION & ENGINEERING, BLDG 2019	23 SRO HIGH-THRUST TEST AREA
11 LRO & NRO FABRICATION & LABORATORY,
BLDG 2002	24 LRO & NRO TEST AREA
12 SRO & NRO FABRICATION & LABORATORY,
BLDG 2004	25 MAGAZINE AREA
	26 SRO RECEIVING COMPLEX, 4900
AREA

Figure 21 - Map of Aerojet-General Sacramento Facility

It is expected that personnel currently providing support to programs sponsored by the NASA, the Air Force, and SNPO (Joint AEC/NASA Agency for NERVA) can be made immediately available for this program. Current manpower forecasts indicate that the required number of highly qualified personnel will be available for the program. This availability, based on a start date of 15 May 1968, will result from the completion of various phases of other programs during the current year and the reduction in requirements for on-going programs after 1 July 1968. Manpower availability beyond 1968 also appears to be more than adequate for continued support of Phase II and the follow-on phases of the program if necessary. In most cases, only 5 to 10% of particular discipline department manpower will be needed where that need is as much as full time.

[(2)e(4)] 4. Design and Engineering Facilities

The principal design and engineering organizations to be used in this program are those at Aerojet's Sacramento 23,000 acre facility illustrated, in part, in Figure 21. Assistance will also be provided by personnel at Azusa and San Ramon. The program will be supported by analytical groups covering such basic engineering disciplines as nucleonics, thermodynamics, stress and structures, and materials. Extensive drafting and blueprint services are available, as are a computing-science organization and a technical information service. These basic discipline groups are housed in three main engineering and administration buildings within walking distance of each other. The combined square footage of these three structures is 631,828. The total Sacramento Plant square footage including shops, laboratories, and test stands is 4,253,946. The Sacramento facility is a self-sustaining complex employing more than 7,000 people; it operates its own police department, fire department, post office, bus line, telephone-teletype facility, library, cafeteria and a full recreation center. In addition, it has its own water supply and water system, power distribution network, planning commission, 65 miles of modern paved roads and 7-1/2 miles of railroad spurs.

A description of unique facilities related to this study activity also housed in Sacramento follow.

a. Engineering R&D Laboratories

The engineering R&D laboratories are divided into three individual laboratories: mechanical; electrical-electronic; and component evaluation. They contain facilities for assembly, development, and testing of mechanical and electrical control components, assemblies, and systems for engines and motors.

(1) Mechanical Laboratory

The Mechanical Laboratory consists of several areas, each containing specialized equipment for a particular phase of the assembly, development, and testing of mechanical controls including valves, seals, filters and actuators. Areas are devoted to environmental and servo-system testing, to water-flow calibration, and to compressible-fluid testing.

(2) Electrical-Electronic Laboratory

The Electrical-Electronic Laboratory is equipped for the testing, evaluation, and qualification of experimental, prototype, and deliverable components and subsystems. Breadboard systems are assembled and tested and experimental components are developed to meet special program requirements. Typical of these are engine thrust controls, ignition systems, malfunction detection systems, engine sequence and protective controls, and ground support equipment. The laboratory is equipped to perform precision voltage, current, and frequency measurements.

A separate facility is available for the development and operation of electro-mechanical servo systems. This facility is equipped with special test equipment designed to provide input signals to, and analyze signals from, servo-actuated systems. Signal analysis equipment has the capability to measure, compute, and record data pertinent to transient analysis, velocity error, position error, and frequency response testing.

(3) Special Projects Laboratory

In order to provide the advanced specimen processing and testing facilities required in the evaluation of the mechanical and metallurgical properties of high-strength alloy materials, a research and development specimen fabrication and testing facility has been established within the special projects laboratory. The purpose of this function is to provide the type of advanced, precision, specimen processing, heat treating and testing facilities required in the future program. These include machining, welding, grinding, and nondestructive testing facilities capable of processing all types of test specimens.

The stress-wave emission data acquisition and analysis capability available in this laboratory is unique and more extensive than any other known laboratory in the United States. This capability has been developed at an expense to the Corporation and will be available for application to FFTF programs.

There are essentially three major capabilities available. The first consists of basic tape recording, charge amplifiers, accelerometers, and band pass filters, which comprise two "portable" systems employed during the tensile testing of specimens using the laboratory equipment described above. The major components of this system are Ampex CP 100 and SANGAMO Model 3250 tape recorders.

In addition, a closed-loop-dead weight loading test facility has been recently designed and built expressly for long-time environmental testing in which SWAT is employed for detecting and monitoring flaw growth in structural metals. The unique components include a load frame-concrete base test rack which is insulated from sound and ground-transmitted vibrations which may complicate the detection and recording of the very small amplitude stress-wave emissions ($<0.01g$) associated with environmentally induced cracking in structural metals. In addition, a closed-loop tape recording system has been designed and built for use with this test facility. This system continuously monitors the outputs of up to four sensors simultaneously, separates extraneous noises from real stress waves, and when real stress waves are detected, time indexes their occurrence while automatically actuating a "slave" tape recorder. The stress-wave emission (SWE) is transferred from the closed loop to the tape recorder which is then shut off and the SWE erased from the continuous loop. This test facility is extremely valuable for long-time test periods, since it permits economical, automated testing of multiple specimens without the requirement for a test technician in constant attendance.

The third major SWAT capability is an Advanced 16 Channel Test System. This universal test system has been developed at Aerojet and includes the use of a digital computer to process, analyze, and display the SWE data. The digital information can be handled in two modes: the first is a data logging method which presents all the information processed through the digital logic networks to a visual display and simultaneously records this data and the time at which it occurred on punched paper tape, and as a typewritten record. The primary use of this data logging method is for long-term surveillance of noncritical structural components, time dependent material properties tests, and other applications where the using agency does not require an immediate response action.

The second mode in which the stress-wave data may be handled is more universal in nature. In this mode, all of the digital stress wave data and any other pertinent information, such as temperature, pressure, load, strain, etc., is furnished internally to a general-purpose digital computer. This general-purpose computer can be programed to operate on the data in any manner desired by the user. Triangulation programs for arbitrary geometry test specimens have been developed so that flaw location can be automatically furnished as data output. Through this system, all possible data handling techniques can be automatically accomplished and displayed, in real-time, so that decisions or actions may be taken. The computer can also be scheduled to make decisions and react, responsively, to any pre-established situation, on applications where long-term surveillance of critical components is of primary importance.

b. Computing Facilities

The Computing Sciences Division is staffed and equipped to solve computer-related engineering or scientific problems. This division provides the data-processing service necessary to reduce masses of analysis information to meaningful terms, as well as supporting management and project offices with computer systems.

Processing services utilizes IBM 360/65, 360/40, 360/30, 360/20, 7044, and 1130 digital computers or analog computers, as required by the problem or process.

The IBM Model-65 digital computer is available for exploring scientific and engineering problem areas. The machine is utilized in the design of propulsion systems for problems relative to the development of rotating machinery; nozzle design and evaluation; fluid flow; injector design; and heat transfer. The 360 computer has a 512,000-byte memory system, four 2311 disk drives, a 15-tape drive, and a 0.75-microsec cycle. It is supported by a 2540 card reader-punch that punches cards at the rate of 300 cards per minute and has a card read speed of 1000 cards per minute. Also in support is a 1403 printer that prints at the rate of 1100 lines per minute.

Off-line requirements are handled with an IBM 360 Model 30, driving three 1403 printers, five 2400 tape drives, and a 2540 card reader-punch. The Model 30 has an 8000-byte memory and a 2.5-microsec cycle time. A second Model 30 has five 2400 tape drives, two 2311 disk units, one 2540 card reader-punch, and a 16,000-byte memory.

An 1130 digital computer is also available as an engineering tool to prove concepts and theories before inclusion in the larger programs to be run on the 360 computer. The 1130 computer will punch 100 cards per minute, read 400 cards per minute, and print 900 lines per minute. This machine has an 18-microsec access time. Using these facilities, programs have been developed in such areas of rocket-engine component design as thermodynamics, engine simulation, test-data reduction, stress analysis, transient and steady-state engine performance analysis, and flight simulators.

A 7044 digital computer is available to support the proposed program by providing data for milestone reporting, project cost reports, timekeeping, payroll, and other related administrative functions. This machine has a 32,000-word memory system, a 10-tape drive, two 1301 disks, and a 2-1/2-microsec access cycle.

In addition, computing capabilities outside of the Computing Sciences Department but inside the Nuclear Division in Sacramento consists of the following:

(1) Analog Computing Facilities

Two Comcor CI-5000 consoles;
Two Electronic Associates 231R V consoles;
Two Electronic Associates 131R consoles; and
One Electronic Associates 24D console.

Total equipment available in the machine frames is:

(a) Operational amplifiers, 1090; (b) electronic multipliers, 264; (c) adjustable diode function generators, 39; (d) special fixed-diode function generators, 84; (e) comparators, 62; (f) limiters, 62; (g) servo-set potentiometers, 820; and (h) hand-set potentiometers, 248.

Augmenting this capability is a hybrid (analog/digital) computer that combines a Comcor CI-5000 analog console with a SDS Sigma-5 digital computer which is to be activated in June 1968. Additional analog equipment with this computer includes 203 operational amplifiers, 192 servo-set potentiometers, and 32 electronic multipliers. Interconnecting linkage consists of 32 analog-to-digital lines and 32 digital-to-analog lines, plus floating-point conversion circuitry. The Sigma-5 digital computer includes a core storage capability of 16,384 words with a compliment of 32 supporting registers. Operational controls will link the two present CI-5000 consoles with the hybrid system.

(2) ESIAC

The ESIAC is a potential-plane analog device used for feedback control system design using root-locus techniques. The operation is based on the concept of a pair of potential-plane "factor analogs" in which voltage measurements at the zeros and poles of a complex variable function are used for calculation.

Among the principal applications of the ESIAC in the design of feedback control systems are: (a) root-locus plotting; (b) frequency response plotting; (c) polynomial factoring; and (d) residue evaluation. The ESIAC can also be used for synthesis of the transfer function from empirical magnitude and angle data. This process, however, is based on a trial-and-error procedure. The computer has semi-automatic plotting facilities to provide direct graphical output for frequency response and root-locus plots.

(3) Research Laboratory

The Research Laboratory section of the Nuclear Systems organization provides laboratory support to the organization as well as to the NERVA Instrumentation, and Radiation Effects programs. The laboratory is completely equipped with the latest high accuracy test equipment. Accuracy of the test equipment is maintained by periodic calibration traceable to the Bureau of Standards. Highly qualified technicians are permanently assigned for systems research that is conducted in the laboratory.

c. Technical Library

To meet the need for a complete technical information service at its Sacramento facility, Aerojet maintains a well-equipped technical library. The library collection affords extensive coverage of the following fields; the physical sciences, engineering, nucleonics, and aerospace technology. The acquisitions policy of the library is designed to ensure that all pertinent technical literature will be acquired as promptly as possible.

Holdings include more than 20,000 books, 1900 bound periodicals, and 61,000 technical reports. The library subscribes to 650 technical journals and has excellent work relationships with many large research libraries for interlibrary loans. In addition to its collection of printed reports, the library maintains files of NASA microforms and other microfilm. A collection of vendor catalogs is maintained, and the library subscribes to Vendor Specs Microfilm File (VSMF) service and the Thomas Micro-Catalogs service. Microfilm readers with printout attachments are available to make hard copies as needed.

The library has indexed the more than 61,000 external and internal technical reports in its collection. This literature-retrieval system is stored on magnetic tape and used on an IBM 360 computer. A literature search on the computer can accommodate 52 separate coordinations at a single pass of the tape file and requires less than two minutes of machine time. In addition to this local capability, the Corporation Technical Information Center at the Azusa facility provides a source for ready access to all technical information available within any of Aerojet's several plants. A literature search can be obtained in a matter of minutes and the abstracts pulled.

To supplement these literature-retrieval systems produced by Aerojet, the library utilizes, on local computers, completely updated duplicates of the magnetic-tape reels used in the NASA Technical Information Facility literature-retrieval system. The Sacramento facility is thus afforded rapid in-depth literature searching for literature abstracted in NASA's Scientific and Technical Aerospace Reports and in A.I.A.A.'s International Aerospace Abstracts. In addition, searches can be obtained from the Defense Documentation Center (formerly ASTIA) as needed.

Competent professional librarians are available to assist personnel in making searches with the computer retrieval systems and in searching the open literature. The library maintains current and retrospective files of the pertinent published indexes. In addition to those indexes noted above, the following are some of the more important indexes maintained and utilized: DTIC (ASTIA) Technical Abstract Bulletin, Chemical Propulsion Abstracts (compiled by SP-10), ASTIA Abstracts, Chemical Abstracts, Nuclear Science Abstracts, Technical Translations, Engineering Index, Applied Science and Technology Index, Applied Mechanics Reviews, and ASM Review of Metal Literature. The library also has more specialized indexes and a large collection of bibliographies on special subjects.

d. Technical Document Center

In order to expedite reference acquisition and storage efficiency, the Technical Document Center was created by the Sacramento Facility's Nuclear Rocket Operations. Although this center is not a library, it functions much like one in conjunction with the Technical Library and its data retrieval. The Technical Document Center is staffed with expert clerical personnel equipped to retrieve in minutes documents stored in the Center which are related to nuclear programs. Holdings of this Center both in the classified and unclassified literature include documents from the following AEC laboratories and/or contractors: Atomics International, Atomic Energy Commission, Westinghouse (WAPD & WANL), AMF, Argonne National Laboratory, General Electric, Applied Physics Laboratory, BMI, BNL, University of Chicago Metallurgical Laboratory, Los Alamos Scientific Laboratory, University of California Lawrence Radiation Laboratory, Union Carbide Nuclear Company, ORNL, National Lead Company, G. M. Allison Division, Gulf General Atomic, Sylvania Corning Nuclear Corporation, Martin Nuclear Division, NUS, AECL, Martin-Marietta Company, USNRDL, Nuclear Metals, Inc., AERE, Georgia Nuclear Labs - Lockheed, PPeCo, ANS, EG&G, Hewlett-Packard Company, AIF, Bechtel, Idaho Nuclear Corporation, LMEC, J. Nuclear Materials, Radiation Solid State Laboratory, and Electronic Research Laboratory, plus others.

[(9)] 5. Outside Assistance

The Aerojet-General Corporation plans to perform the study program with current employees. Assistance from sources outside the company will not be required.