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WANL-TME-1855

MASTER

Westinghouse Astronuclear Laboratory

ENGINEERING DATA AND DESIGN REVIEW
(JULY 16 AND 17, 1968)

(TITLE UNCLASSIFIED)

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Mr. J. I. Dooling
NERVA Subcontract Manager
Nuclear Rocket Operations
Department 7140
Aerojet-General Corporation
P.O. Office Box 15847
Sacramento, California 95816

Subject: WANE-TV-1855, "Log Cabin and De 'Junk v.
(July 16 and 17, 1963)" (L), dated Aug. 22, 1963

Transmitted herewith for your information are two (2) copies of the subject report.

W H R D, JR / M K W.

W. H. Arnold, Jr.
Program Manager
NERVA Medical Subsystem

Enclosures (2)

9/18-1

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PM-WEB-356

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T. A. Mantia, WANL Resident at AGC, w/1 enclosure

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Reactor Branch				✓✓✓	
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ENGINEERING DATA AND DESIGN REVIEW (JULY 16 AND 17, 1968)

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<u>C-R.D.</u>	
<u>JV Hingley</u>	<u>8-22-68</u> ✓
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AGENDA
FOR
ENGINEERING DATA AND DESIGN REVIEW

(July 16 and 17, 1968)

Tuesday, 7-16-68

I.	INTRODUCTION	W. H. Esselman
II.	ENGINE SYSTEMS REQUIREMENTS	S. Varga - AGC
III.	NERVA NUCLEAR SUBSYSTEM
(CEI CP677555)	P. M. Furr
A.	Introduction of Reactor Assembly	F. D. Retallick
B.	Reactor Performance Requirements
and Characteristics	
	1. Stress	D. F. Miller
	2. Nuclear	R. A. Doncals
	3. Thermal	B. L. Pierce
C.	Reactor Detail Design	
	1. Cluster Assembly and
Miscellaneous Hardware
(ECC-EC677558)	J. W. Fisch
	2. Cluster Hot End Support
Hardware (ECC-EC677557)	J. E. Johnson
	3. Support Stem
(ECC-EC677561)	D. Black
	4. Support Stem Feed
(ECC-EC677561)	D. C. Thompson
	5. Fuel Element
(ECC-EC677566)	J. Swanson/L. Boman

C. Reactor Detail Design (cont'd.)

6. Core Periphery
(ECC-EC677564)

J. W. Fisch

7. Lateral Support
(ECC-EC677563)

J. W. French

8. Reflector & Axial
Support (ECC-EC677559)

J.W.French/R.P.
Vijuk/D.F.Miller

Wednesday, 7-17-68

C. Reactor Detail Design (cont'd.)

9. Gang Drum Drive
Mechanism (ECC-EC677560)

D. Weisnee

10. Shields (ECC-EC677562)

W. J. Schlitt/
S. T. Friedman

11. Poison Wires
(ECC-EC677567)

J. L. Pierce

12. Summary - Design Recommendations

F. D. Retallick

D. Structural Support Coolant Supply System

Overall performance/design requirements,
configuration layout, test plan and baseline
assumptions (CEI-CP677575)

G. L. Hohmann

1. SSCSS Actuator
(ECC-EC677576)

P. R. Greenaway

E. Reactor Control and Instrumentation

1. Reactor Control
System (ECC-EC677568)

H. H. Norman

2. Control and Diagnostic
Instrumentation (ECC-EC677565)

A. E. Primm

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E. Reactor Control and Instrumentation (cont'd.)

3. Control Drum Actuator
(CEI-CP677585)

G. L. Hohmann/
D. D. Armstrong

F. Test Facilities

1. EML - Test Rig Requirements

C. L. Meuche

2. Corrosion and Fluid Flow Test
Rig Requirements

H. J. Fix

3. Nuclear Test Rig Requirements

W. P. Kovacek

IV. SUMMARY

W. H. Esselman

Summarize the agreements from the meeting,
present summary of plans leading to PDR and
discussion of action items from the meeting.

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SUMMARY OF ED AND DR MEETING

(U) There was concurrence that the channel of communication between WANL and SNPO-C on specifications and other data items was to be between R. F. Dickson and O. L. Olson.

(U) The purpose of the meeting was to present the design alternates and the proposed design approaches for the NERVA Nuclear Subsystem. The requirements used were the October, 1967, Program Requirements Document with differences between the October requirements and the April, 1968, requirements being pointed out in the individual presentations.

(U) The engine system requirements were presented by Mr. S. Varga of Aerojet and the Nuclear Subsystem by Mr. P. Furr of WANL. These presentations included preliminary state point charts and a review of the Program Requirements Document.

(CRD) The reactor assembly detail requirements, design approaches, and the recommended design approach were presented. The summary of the recommended approaches was:

Cluster Assy. and Misc. Hdw.

Cold end secondary support with
standoff from aft end hardware.

Support Stem Assy.

Straight-through stem.

Cluster Hot End Support Hdw.

Pedestal support through the
central element with fuel element
standoff, backup design with gathered
hole keyed fuel element.

Fuel Elements

- 1) Low expansion, low void,
no additives--NbC - GEM,
GED coatings.
- 2) Zirconium carbide coatings.
- 3) Development of high expansion fuel.

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(CRD) Core Periphery	Cold Filler strip design and a 0.155 inch pyrofoil wrapper.
Lateral Support System	Angle seal segments.
Reflector and Axial Support System	Rings with radial slots with continued effort on alternate design features.
Ganged Drum Drive System	Ganged drum drive system supported independent of reflector and located forward of the extension shield.
Support Stem Feed and Discharge System	Combined support plate and plenum feed. Central Shield located above the support plate, ganged drive mechanism located above the extension shield, and provision for adjusting the thickness of the central and extension shields and the addition of side shield, if required for manned applications, Provision shall be made for attaching boral liners around the dome and around the periphery of the reflector as required.
Anti-Criticality Poison Wires	Flexible wires containing sintered beads.
Reactor Controls	Proceed with development of logic required to implement computer monitored redundancy.
Control & Diagnostic Instrumentation	Proceed with instrumentation development emphasizing reliability.
Control Drum Actuators	Proceed with development of the G. E. design.

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Structural Support Coolant
Supply System

Investigate the Rocketdyne J-2 actuator
candidate and continue studies to identify
requirements.

(U) Presentations on the agenda which were not completed or given were: poison wires, structural support coolant supply system, control and diagnostic instrumentation, control drum actuators and test facilities requirements.

(U) Comments on the meeting will be coordinated and officially transmitted by Mr. E. Bosse of SNPO-C.

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**75,000-LB-THRUST
NERVA FLIGHT ENGINE**

EFFECT OF STRUCTURAL COOLANT FLOW RATE

STRUCTURAL SUPPORT FLOW RATE LB/SEC	NOZZLE FLOW RATE LB/SEC	PUMP DISCHARGE PRESSURE PSIA	NOZZLE ΔP PSID	ΔI_{sp} SEC
30	61	935	195	0
15	76	1008	246	-1.5
10	81	1042	270	-2.2
5	86	1067	290	-3.0

NSS DESIGN REQUIREMENTS
ESTABLISHED BY AGC/WANL
AS ALLOCATED FROM PRD

6

RELIABILITY (0.997)

SAFETY

MAINTAINABILITY

CLEANLINESS

LEAKAGE

SHIELDING

STORAGE LIFE

TRANSPORTABILITY

WEIGHT

NSS - STATE POINTS (ICD)

MAJOR NSS DESIGN REQUIREMENTS SOURCE DOCUMENTS

- PROGRAM REQUIREMENTS DOCUMENT
- SYSTEM ENGINEERING DOCUMENTATION
- ENGINE CEI SPECIFICATION

INTERFACE CONTROL DRAWINGS
(LOADS, ENVELOPE, ELECTRICAL,
MECHANICAL, STATE POINTS)

- LOADS DOCUMENT
- RADIATION LEVEL DOCUMENT
- TEMPERATURE DISTRIBUTION DOCUMENT
- STRUCTURAL DESIGN REQUIREMENTS
DOCUMENT (SNPO-C-1)

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NERVA ENGINE STEADY STATE VALUES
75K NERVA PD = 945 TC = 4446R

- ENGINE · PC = 450.0 · THRUST 75000 LBS. · IMPULSE 823.39 SEC
· POWER LEVEL = 1552.9 MW TURBOPUMP = 19000. RPM
- TURBOPUMP OVERALL
 - SHAFT POWER, MW 5.9746
 - TURBINE EFFICIENCY 0.5500
 - PUMP EFFICIENCY 0.6440

STATE POINT DESCRIPTION	FLOW LBS/SEC	TOTAL PRESSURE	TEMPERATURE
DEWAR OUTLET	91.08	30.0	40.0
PUMP OUTLET	90.58	945.0	55.6
TPA BEARING COOLANT	0.50	945.0	55.6
STRUCTURE SUPPORT INLET	26.80	945.0	55.6
STRUCTURE BYPASS INLET	3.20	945.0	55.6
NOZZLE MANIFOLD INLET	60.58	905.0	55.6
NOZZLE OUTLET	37.43	705.0	210.6
SKIRT OUTLET	20.15	705.0	210.6
BOLT COOLANT OUTLET	3.00	705.0	55.6
REFLECTOR INLET	57.87	705.0	202.9
REFLECTOR OUTLET	57.87	654.0	313.5
CORE INLET	87.87	620.0	316.6
CORE OUTLET	87.87	450.0	4500.0
NOZZLE CHAMBER	86.60	450.0	4446.0
MAIN NOZZLE EXIT	86.60	450.0	4408.8
DILUENT BLEED INLET	2.71	705.0	202.9
HOT BLEED INLET	1.27	450.0	4446.0
TURBINE INLET	3.98	292.2	1660.0
MAIN TURBINE EXIT	3.98	38.3	1258.1

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T_c - 4500°R MIN
 P_c - 450 PSIA NOM.

ENDURANCE

FLIGHT	50 MIN	(1-10 CYCLES)
PRE-QUAL	75 MIN	(IN MULTIPLE CYCLES)
QUAL	50 MIN	(ONE & MULTIPLE CYCLES)

THROTTLABILITY 450 TO TBD PSIA @ 4500°R
 MAX RATE 50 PSI/SEC FOR DURATION OF TBD SEC

STARTUP & SHUTDOWN TRANSIENT RAMPS - MAX RATES

T_c - 150°/SEC
 P_c - 50 PSI/SEC

PRESENTATION FOR ENGINEERING DATA AND DESIGN REVIEW

III. NERVA Nuclear Subsystem

A. Requirements

1. Introduction

(U) Good morning. My part of this presentation will cover the overall requirements, a conceptual system and the systems analysis effort that should be completed prior to Preliminary Design Review.

(U) We have prepared Part I detail specifications for the Contract End Items and the designated Engineering Critical Components. As you know these Part I specifications contain the requirements for performance, design, test and qualification of the item. In other words, these are "design to" documents. They are not intended as a design freeze but represent a baseline for controlling the "design to" requirements and changes thereto.

(U) The format used in the preparation of all of our Part I specifications is that shown in AFSCM 375-1. We followed this format exactly to the fourth indenture level and used the definitions of terms shown in Exhibits II and VI of AFSCM 375-1.

(U) 2. Requirements

The next few slides will illustrate the Significant Design Requirements for the NERVA Nuclear Subsystem. These requirements have been based upon the Program Requirements Document prepared by SNPO dated October 10, 1967 and, to some extent, the results of the Engine Systems Task Force meetings. The slides also point out areas of difference between the requirements, as stated in the Nuclear Subsystem Part I specification, and the SNPO Program Requirements Document of April 29, 1968. It is our intent to fact the changes into the specification and have it back to you for review prior to Preliminary Design Review. The third column on the slide shows the source of the baseline assumption.

(U) a. Design Conditions

The Nuclear Subsystem design conditions are a nominal thrust chamber temperature of 4500°R at a thrust chamber pressure of 450 psia and a flow rate of approximately 88 lb/sec including the hot bleed. The flow rate really is subject to change and is controlled by the state point diagram between WANL and AGC.

As you see, the April 29 PRD designates this as rated conditions and requires a minimum chamber temperature of 4500°R rather than nominal.

(U) b. Endurance

The Nuclear Subsystem has two endurance requirements. One is the mission requirement of fifty minutes at full power which we have designated as the primary endurance requirement. The other is the ground test endurance of seventy-five minutes and we have designated this a secondary endurance requirement.

As you see, these requirements are the same as those stated in the April 29 PRD.

(U) c. Number of Starts

The system is being designed to be capable of meeting the mission endurance, of fifty minutes, including ten starts to design conditions. The time of operation for each cycle may vary.

Again, there is no difference between this requirement and the April 29 PRD.

(U) d. Start-Up

We are designing the Nuclear Subsystem to be capable of two modes of start-up; the high impulse start and the high thrust start-up. Start-up

is defined as the time required from the initiation of propellant flow to the achievement of design conditions. We have also defined the completion of bootstrap as a chamber temperature of 1000°R and a chamber pressure of 60 psia.

(U) For the high impulse start, the NSS is being designed to go from the completion of bootstrap to a chamber temperature of $4500 + 100 - 300^{\circ}\text{R}$ and a chamber pressure consistent with other limitations in a maximum of 23 seconds. This is equivalent to a temperature ramp of $150^{\circ}\text{R}/\text{sec}$. The chamber pressure will then be ramped to the design conditions at a rate of 10 psi/sec while maintaining the chamber temperature.

(U) The difference between our present design approach and the April 29 PRD is the pressure ramp. Some preliminary analysis has been done on the 50 psi/sec and will be discussed later.

(U) The high thrust start requires that the Nuclear Subsystem be ramped from completion of bootstrap to design conditions in 23 seconds. Again this corresponds to an equivalent temperature ramp of 150°R .

(U) e. Shutdown

Regardless of the start-up mode, shutdown is always accomplished at high impulse. In other words, we reverse the high impulse start-up path. Chamber-pressure is reduced to a point consistent with Nuclear Subsystem limitations at a rate of 10 psi/sec while maintaining the chamber temperature at $4500^{\circ}\text{R} + 100^{\circ}\text{R} - 300^{\circ}\text{R}$. At this point, the control drums are rotated to their most poisoned position and chamber temperature is reduced to 1500°R in a maximum of 20 seconds. Heat produced subsequent to this time is removed at an average thrust chamber temperature of 1500°R .

Again, the pressure ramp is the only difference between our stated requirements and those of the April 29 PRD. As I stated before, we are currently looking at ways to meet this new requirement.

(U) f. Shielding

The NSS shields will be located internal to the pressure vessel and designed for single engine, single module operation, for manned mission applications. A shield task force has been established by SNPO to define these requirements in more detail. WANL is participating on this task force and our design will factor in the Task Force results.

(U) g. Throttling

Throttling, of course, will be performed as a part of the start-up and shutdown requirements. In addition, we recognize the need to be able to retreat to some reduced chamber pressure and/or chamber temperature for a variety of reasons. Therefore, we will define the transient and steady state operating limits of the Nuclear Subsystem by means of an operating map of chamber temperature versus chamber pressure.

We understand that the April 29 PRD is being revised to state that the system must be capable of throttled operation at rated chamber temperatures and at chamber pressures ranging from 450 Psia to TBD. The system must be capable of steady state operation at this throttled condition for a TBD length of time.

(U) h. Reliability

The apportioned reliability goal for the Nuclear Subsystem is a probability of 0.997 at a confidence level of 90 percent of meeting mission success criteria for 10 cycles of operation, a total of 50 minutes at design conditions. We will not demonstrate the confidence level by attribute testing.

We have made a preliminary allocation of this reliability requirement to the components of the Nuclear Subsystem and this allocation is being considered in system and component design.

(U) The NSS reliability was apportioned from the engine requirement of 0.995 and is consistent with the April PRD except for the requirements for crew survival and abrupt loss of thrust. The April PRD has additional requirements that the probability of an engine failure which either causes injury to the crew or damages the spacecraft or prevents return of the spacecraft to Earth be less than 1×10^{-4} per flight. It also requires that for engine failures resulting in abrupt and irreversible loss of thrust, the failure rate during the first thrust cycle not exceed 3×10^{-8} failures/sec. An apportionment of these numbers between the NSS and the non-nuclear components still must be made.

We are currently investigating the design effects of these additional requirements as part of our flight safety and reliability effort.

(U) i. Useful Life

Useful life is defined as the period from time of delivery of the Nuclear Subsystem to the procuring agency until its identity is destroyed by classifying it as salvage and/or it is subjected to cannibalization.

We have further divided this into operating and non-operating life. The requirement for operating life is the capability to perform the mission after being in space one year. This year may or may not occur between the first and last operating cycle.

The non-operating life is the capability to meet the operating life requirements after a ground storage period of two years. This time period includes all the time from acceptance of the Nuclear Subsystem through engine assembly, pre-launch, launch and boost.

The April PRD requires an operating life of up to one year in space prior to power operation plus 30 days between operating cycles. It also requires a non-operating life of five years in a suitable container and six months under the launch pad environment.

(U) i. Preliminary Summation

This concludes the presentation of significant design requirements. In summary, I have shown the requirements as presented in our NSSCEI specification and pointed out where these differ from the April 29 PRD. A thorough analysis of the April 29 PRD will be made to insure that we include all of the requirements in the revision of the Part I detail specification.

(U) 3. Reference Design Approach

Next I will describe a conceptual system. This system is still in the conceptual phase and a major systems analysis effort will be required between now and PDR to firm up component requirements. Briefly, I will describe the system including the mechanical and electrical interfaces at the CEI and major subassembly level. Details concerning the design approach for the components will be discussed by later speakers.

This slide shows a schematic block diagram of the NSS. Conceptually, it shows how the components interface with each other. The components can be divided into three major sub-assemblies; the Reactor Assembly, the Reactor Control System, and the Structural Support Coolant Supply System.

(U) a. Reactor Assembly

The Reactor includes the Cluster and Miscellaneous Hardware, Support Stem, Cluster Hot End Support, Poison Wires, Fuel Elements, Support Stem Plenum, Reflector and Axial Support, Lateral Support System, Core Periphery, and Gang Drive System, and Internal Shields. Some of the primary performance characteristics of this assembly are to:

1. Generate the nuclear power necessary to heat the propellant to 4500°R.
2. Provide sufficient reactivity variation to permit controlled start-up, steady state operation and shutdown.

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3. Provide adequate structural support to meet the environmental requirements imposed by both operating and non-operating conditions.

4. Be capable of meeting both the mission and ground test endurance requirements including the number of cycles.

(CRD) b. Structural Support Coolant Supply System

The Structural Support Coolant Supply System consists of the Structural Support Coolant Valve, Piping and Supports and the Structural Support Coolant Valve Actuator. The primary performance characteristics of this system are to:

1. Provide and control support stem coolant flow within the ranges established by the pump discharge pressure and Reactor Assembly constraints.

2. Provide reactivity shimming at start of life.

(U) c. Reactor Control System

The Reactor Control System includes the Reactor and Structural Support Coolant Supply System Controller, the Control Drum Actuator, the Control Instrumentation and the Diagnostic Instrumentation. The primary performance characteristics of this system are to:

1. Provide a control drum demand for controlled start-up, steady state operation, and shutdown within the apportioned tolerances.

2. Provide an automatic flow demand during cooldown.

3. Provide signals to the safety and diagnostic system.

4. Provide the position demand for the Structural Support Coolant Valve.

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5. Provide malfunction detection which will introduce redundant control circuits or retreat to other operating conditions such that either:

- a. The mission is completed.
- b. The mission is altered with partial completion of objectives.
- c. The mission is aborted with the crew returned safely to Earth.
- d. The mission is aborted with the NSS shutdown without danger to the crew and with acceptable ground hazards.

6. Position the control drum bank to provide the necessary reactivity control.

That concludes my brief description of the baseline system. The detail design requirements for each of the components will be discussed by later speakers.

(U) d. Systems Requirements Analysis

Next, I will discuss some of the overall systems analysis work that must be done before Preliminary Design Review. The most urgent task is to perform a thorough Systems Requirements Analysis of the April 29 Program Requirements Document to determine what the additional requirements are. We must then determine the impact of these requirements on the program and prepare incompatibility ECP's where necessary.

For example, as I showed earlier we have been designing for a nominal thrust chamber mixed mean gas temperature of 4500°R which is consistent with the October 10, 1967 guidelines. The April PRD requires a

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- (U) minimum mixed mean chamber inlet temperature of 4500°R . The change in requirement from nominal to minimum has significant effects on this system since the change in effect moves the nominal value upward half the tolerance band with and results in higher temperatures throughout the reactor assembly. This requirement also means that the mixed mean thrust chamber temperatures cannot be less than 4500°R for any finite period of time after having achieved rated conditions. The effect of these changes along with all the others will be determined as a part of this overall systems analysis.

This slide illustrates the steps which will be followed in performing this analysis.

The NERVA program requirements are delineated in the NERVA Program Requirements Document dated April 29, 1968, prepared by SNPO. Requirements for the NSS will be derived from the NERVA Engine Specification. These requirements will be analyzed on a functional basis by the preparation of Functional Flow Diagrams. These diagrams do not attempt to define hardware but describe functionally what the hardware must do. The functions are expanded to the detail necessary to determine the design requirements resulting from the function.

The functions are then individually analyzed on a requirements allocation sheet. This analysis tells why the function is necessary and why it appears in the sequence of events at this time. The design requirements resulting from these functions (and/or sub-functions) are then determined.

At this time certain Trade Studies will be performed. These Trade Studies will be on a fairly gross level, to the detail, necessary to determine overall design approaches.

(U) The design requirements will then be reviewed and allocated to the hardware, software, personnel or facility that will have to meet these requirements. At this time, the definition of CEI's and ECC's will start to crystallize and a specification tree can be drawn. These design requirements will then be recapped on a design sheet for each CEI and ECC.

The way in which WANL intends to prove to SNPO that we have met each of these requirements will then be developed. This verification can be done by inspection, analysis, demonstration or test. Once completed, the design sheets will be used to revise the Part I detail specifications.

As the design sheets are being prepared, requirements for additional trade studies will become apparent. These will be made and the results incorporated into the design sheet.

Since Part I Detail specifications are a forcing function on design, they will then be compared with the functional flow diagrams.

This loop must then be kept closed throughout the design process through overall system analyses to insure that validated system requirements and only those requirements are being met.

(U) f. Conclusion

This concludes my part of the presentation. I have presented the significant requirements for the Nuclear Subsystem and have shown the differences between these stated requirements and the April 29 PRD. As I said, these differences will be resolved prior to resubmission of the specifications for approval.

I also discussed briefly a conceptual design that appears to be an approach to meeting the requirements and the systems analysis effort necessary prior to Preliminary Design Review.

NSS SIGNIFICANT DESIGN REQUIREMENTS

CEI Specifications

April 29, 1968, P.R.D.

Source of Baseline Assumptions

Design Conditions

(Rated Conditions)

$T_c = 4500^\circ R$ Nominal

$T_c = 4500^\circ R$ (Minimum)

October 10, 1967, PRD

$P_c = 450$ psia

$P_c = 450$ psa

$\dot{W} \cong 88$ lb/sec (Including Bleed)

$\dot{W} \cong 88$ lb/sec (Including Hot Bleed)

Endurance

Mission - 50 min.

Same

Engine Systems Task Force Meetings

Ground Test - 75 min.

October 10, 1967, PRD

Number of Starts

Ten of varying duration

Same

October 10, 1967, PRD

Start-Up

High Impulse:

Temperature Ramp of $150^\circ/\text{sec}$

Same

October 10, 1967, PRD plus Engine

Pressure Ramp of 10 psi/sec

50 psi/sec

Systems Task Force Meetings

NSS SIGNIFICANT DESIGN REQUIREMENTS (CONT'D)

<u>CEI Specifications</u>	<u>April 29, 1968, P.R.D.</u>	<u>Source of Baseline Assumptions</u>
High Thrust:		
Temperature Ramp of 150°/sec	Same	
Corresponding Pressure Ramp (17 psi/sec)		
Shutdown:		
Temperature Ramp = -150°/sec	Same	October 10, 1967, PRD plus Engine
Pressure Ramp = 10 psi/sec	-50 psi/sec	Systems Task Force Meetings
Shielding		
Single Engine, Single Module	Shield Task Force	October 10, 1967, PRD plus Engine
Manned Mission		Systems Task Force Meetings
Throttling		
Steady State and Transient Operating Limitations to be Defined by a Map of Tc Vs. Pc	Operate at a <u>TBD</u> Pc at maximum Tc for a <u>TBD</u> length of time	October 10, 1967, PRD plus Engine Systems Task Force Meetings

NSS SIGNIFICANT DESIGN REQUIREMENTS (CONT'D)

<u>CEI Specification</u>	<u>April 29, 1968, P.R.D.</u>	<u>Source of Requirement</u>
Reliability		
0.997 probability of 50 min @ full power including 10 starts.	Same Plus Crew Survival and Loss of Thrust	Apportionment of Total Engine Requirement of 0.995.
Useful Life		
Operating - One Year in Space Which May or May Not Occur Between the First and Last Start.	One Year in Space Before a Power Operation Plus 30 Days Between Cycles.	October 10, 1967, PRD
Non-Operating - Two Years Including Engine Assembly, Pre-Launch Checkout, Launch and Boost.	Five Years Ground Storage in a Suitable Container. Six Months Under Pad Environment.

The System Engineering Process

REACTOR STRUCTURAL REQUIREMENTS AND CHARACTERISTICS

OUTLINE

SUMMARY OF NSS - CEI STRUCTURAL REQUIREMENTS

SUMMARY OF STRUCTURAL CHARACTERISTICS

STEADY STATE CHARACTERISTICS

TRANSIENT CHARACTERISTICS

STRUCTURAL ENVIRONMENT DRAWINGS

INTERNAL LOADS (REACTOR OPERATION) (981D519)

PRELIMINARY VIBRATION AND NOISE ENVIRONMENT
(SHIPPING, HANDLING, AND BOOST) (981D524)

REACTOR STRUCTURAL REQUIREMENTS FROM NSS - CEI

<u>ITEM</u>	<u>REQUIREMENTS</u>
APPLICABLE DOCUMENTS 2.	SNPO-C-1, REVISION 2, "STRUCTURAL DESIGN SPECIFICATION.
RELIABILITY 3.1.2.1	THE APPORTIONED RELIABILITY GOAL FOR THE NSS SHALL BE A 0.997 PROBABILITY AT A CONFIDENCE LEVEL OF 90% OF MEETING MISSION SUCCESS CRITERIA FOR 10 CYCLES OF OPERATION, A TOTAL OF 50 MINUTES OF OPERATING LIFE AS DEFINED IN 3.1.2.3.1 AND UNDER ENVIRONMENTAL CONDITIONS AS SPECIFIED IN PARAGRAPH 3.1.2.4.
STEADY ACCELERATION 3.1.2.4.3.1	THE NSS SHALL BE DESIGNED TO WITHSTAND A STEADY ACCELERATION NOT TO EXCEED +6G AND -4G ALONG THE THRUST AXIS AND 3G IN THE LATERAL DIRECTION. POSITIVE ACCELERATIONS ARE DEFINED AS THOSE ACCELERATIONS IN THE DIRECTION OF FLIGHT.
SHOCK 3.1.2.4.3.2	THE SHOCK LOADING ENVIRONMENT IS LESS THAN VIBRATION LOADING.
VIBRATION 3.1.2.4.3.3	THE LOADS RESULTING FROM VIBRATION ARE LESS THAN THOSE FOR STEADY ACCELERATION AS SPECIFIED IN PARAGRAPH 3.1.2.4.3.1

SUMMARY OF STRUCTURAL CHARACTERISTICS

OUTLINE

REFERENCE DESIGN STARTUP FORCES

REFERENCE DESIGN SHUTDOWN FORCES

REFERENCE DESIGN STARTUP DISPLACEMENTS

REFERENCE DESIGN SHUTDOWN DISPLACEMENTS

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REFERENCE DESIGN - STARTUP FORCES

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REFERENCE DESIGN STARTUP DISPLACEMENTS

612537 - 8B

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REFERENCE DESIGN - SHUTDOWN DISPLACEMENTS

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INTERNAL LOADS (REACTOR OPERATION)

981D519

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INTERNAL LOADS (REACTOR OPERATION)

981D519

HIGH SPECIFIC: IMPULSE STARTUP AND HIGH SPECIFIC IMPULSE SHUTDOWN

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INTERNAL LOADS (REACTOR OPERATION)

981D519

HIGH SPECIFIC IMPULSE START UP AND HIGH SPECIFIC IMPULSE SHUTDOWN AND COOLDOWN

LOCATION	PARAMETER	INITIATION OF FLOW		INITIATION OF CHAMBER TEMP. RAMP		DESIGN CHAMBER TEMP. & PART PWR		DES. CHAMB. TEMP. & FLOW START OF LIFE		DES. CHAMB. TEMP. & FLOW END OF LIFE		DESIGN CHAMBER TEMP. & PART PWR		TERMINATION OF POWER		TERMINATION OF FLOW OF INITIAL PART OF COOL-DOWN		INITIATION OF FLOW FOR COOL-DOWN PULSE	
		A		B		C		D		E		F		G		H		I	
		NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI	NOM	2 σ VARI
45 SUPPORT STEM FWD (PERIPHERY)	F _A D _R D _A			143 -.050 .042		385 -.049 .076		570 -.049 .074		571 -.049 .072		381 -.045 .069		381 -.045 .069					
40 SUPPORT STEM FWD (CENTER)	F _A D _A																		
10 AFT RING	F _R F _A D _R			96.9K		187K		258K		258.1K		185K		185K					
20 REFLECTOR FORWARD END	F _R F _A M _T D _R D _A			49.2 -.011 .055		135K -.029 .068		214K -.028 .065		217K -.028 .064		146K -.027 .062		146K -.027 .062					

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PRELIMINARY VIBRATION & NOISE ENVIROMENT (SHIPPING , HANDLING AND BOOST)

981D524

612537-1B

PRELIMINARY VIBRATION & NOISE ENVIROMENT (SHIPPING , HANDLING AND BOOST)

981D524

LOCATION	GRD. HDL.		SHIPPING		BOOST				GROUND TEST		EQUIVALENT STATIC DESIGN VALUE
	VIBRA.	SHOCK	VIBRA.	SHOCK	STEADY ACC	VIBRA.	ACOUS'	SHOCK	VIBRA.	ACOUS	
10 HORIZONTAL VERTICAL											3 +6,-4
20 HORIZONTAL VERTICAL											3 +6,-4
30 HORIZONTAL VERTICAL											3 +6,-4
40 HORIZONTAL VERTICAL											3 +6,-4
50 HORIZONTAL VERTICAL											3 +6,-4
60 HORIZONTAL VERTICAL											3 +6,-4
70 HORIZONTAL VERTICAL											3 +6,-4

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SUMMARY

ALL STRUCTURAL ANALYSES WILL CONFORM TO SNPO-C-1, REVISION 2 FOR ALL OPERATIONAL CONDITIONS.

THE APPORTIONED RELIABILITY OF EACH CRITICAL COMPONENT WILL BE EVALUATED USING CALCULATED STRESSES AND LOAD VARIATIONS.

INTERNAL COMPONENT LOADS ARE CALCULATED BY USE OF A REACTOR MECHANICAL MODEL.

INTERNAL LOADS WILL BE COMPUTED USING DATA SUMMARIZED ON THERMAL AND FLUID ENVIRONMENT DRAWING.

THE REACTOR IS DESIGNED TO WITHSTAND AN EQUIVALENT STEADY ACCELERATION NOT EXCEEDING +6G AND -4G ALONG THE THRUST AXIS AND 3G IN THE LATERAL DIRECTION.

REACTOR NUCLEAR AND RADIATION PERFORMANCE REQUIREMENTS AND CHARACTERISTICS OUTLINE

SUMMARY OF NSS-CEI NUCLEAR AND RADIATION PERFORMANCE REQUIREMENTS

SUMMARY OF NUCLEAR AND RADIATION CHARACTERISTICS

NUCLEAR AND RADIATION ENVIRONMENT DRAWING (DWG. NO. 981D523)

REACTOR NUCLEAR AND RADIATION PERFORMANCE REQUIREMENTS FROM NSS-CEI

ITEM

REQUIREMENTS

3.1.1.1.1 DESIGN CONDITIONS

- A. THRUST CHAMBER MIXED MEAN TEMPERATURE = 4500°R
- B. THRUST CHAMBER PRESSURE = 450 PSIA
- C. FLOW RATE = 88.7 LB/SEC

3.1.1.1.6 SHIELDING

- A. SINGLE ENGINE, SINGLE MODULE
- B. MANNED MISSION

3.1.2.7.1 GROUND SAFETY

- A. THE NSS SHALL BE POISONED SUCH THAT THE EFFECTIVE MULTIPLICATION FACTOR SHALL NOT EXCEED 0.95 WHEN THE NSS IS FLOODED WITH WATER, LIQUID HYDROGEN, OR ANY OTHER HYDROGENOUS FLUID CREDIBLE IN THE VICINITY OF THE REACTOR.

SUMMARY OF NUCLEAR AND RADIATION CHARACTERISTICS

OUTLINE

CRITICAL CONTROL DRUM POSITIONS

COLD TO HOT REACTIVITY FEEDBACK

HOT POWER DISTRIBUTION

RADIAL POWER DISTRIBUTION DURING LIFE

UTILIZATION OF SUPPORT STEM REACTIVITY CONTROL

INTERNAL AND EXTERNAL RADIATION ENVIRONMENT

CRITICAL CONTROL DRUM POSITIONS

COLD CRITICAL, START OF LIFE	111°
HOT CRITICAL, START OF LIFE	106°
HOT CRITICAL, END OF LIFE	124°
COLD CRITICAL, END OF LIFE	129°
ORIFICE ANGLE	115°

METHOD USED TO CALCULATE COLD-TO-HOT REACTIVITY FEEDBACK

TOTAL NET OPERATING REACTIVITY FEEDBACK DIFFERENCE (NERVA-NRX/EST)	<u>X</u>
OBSERVED NRX/EST REACTIVITY FEEDBACK	<u>Y</u>
	<hr/>
EXPECTED FEEDBACK FOR NERVA	<u>X+Y</u>

COMPARISON OF THE NRX/EST AND NERVA COLD-TO-HOT REACTIVITY EFFECTS

	NRX/EST	NERVA	NERVA-NRX/EST
<u>PROPELLANT EFFECTS</u>			
CORE (\$)	+1.65	+1.37	-0.28
MINIMUM SUPPORT STEM FLOW (\$)		+0.60	+0.60
LATERAL SUPPORT (\$)	+0.36	+0.11	-0.25
REFLECTOR (\$)	+0.07	+0.13	+0.06
	NET PROPELLANT EFFECT (NERVA-NRX/EST) =		+0.13
<u>TEMPERATURE EFFECTS</u>			
EXPANSION (\$)	-0.56	-0.62	-0.06
THERMAL BASE (\$)	-0.27	-0.07	+0.20
U + Nb DOPPLER (\$)	-0.92	-0.98	-0.06
SHIM DOPPLER (\$)	-0.27	-0.20	+0.07
	(\$4.09 TaC SHIM WORTH)	(\$3.0 TaC SHIM WORTH)	
REFLECTOR (\$)	-0.20	-0.10	+0.10
	NET TEMPERATURE EFFECT (NERVA-NRX/EST) =		+0.25
	TOTAL NET EFFECT (NERVA-NRX/EST) =		+0.38

DEVELOPMENT OF NERVA COLD-TO-HOT REACTIVITY FEEDBACK

TOTAL NET OPERATING REACTIVITY FEEDBACK DIFFERENCE (NERVA-NRX/EST)	+0.38\$
OBSERVED NRS/EST REACTIVITY FEEDBACK	-0.77\$
EXPECTED FEEDBACK FOR NERVA AT MINIMUM SUPPORT STEM FLOW	-0.39\$
EXPECTED FEEDBACK FOR NERVA AT NOMINAL SUPPORT STEM FLOW	+0.11\$

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HOT POWER DISTRIBUTION

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VARIATION IN RADIAL POWER DISTRIBUTION WITH DRUM REACTIVITY INSERTION AND SUPPORT STEM FLOW

UTILIZATION OF SUPPORT STEM REACTIVITY CONTROL

THE REACTIVITY CONTROL AVAILABLE IN THE SUPPORT STEMS WILL INITIALLY BE USED TO ADJUST THE CONTROL DRUMS TO THE DESIRED OPERATING POSITION (FLOW TRIMMING).

ANY EXCESS FLOW REACTIVITY REMAINING ABOVE THAT REQUIRED FOR THIS SOL FLOW TRIMMING WILL THEN BE USED TO PARTIALLY MAINTAIN THE CONTROL DRUMS AT A PRESCRIBED ANGLE AS REACTIVITY IS LOST THROUGH CORROSION.

RADIATION ENVIRONMENT

INTERNAL ENVIRONMENT

THE FOLLOWING DATA WERE CALCULATED AT SELECTED REACTOR LOCATIONS:

FAST NEUTRON FLUX ($E > 1 \text{ MEV}$)

THERMAL NEUTRON FLUX ($E < 0.4 \text{ EV}$)

GAMMA RAY DOSE RATE

HEATING RATES IN VARIOUS MATERIALS

EXTERNAL ENVIRONMENT

THE EXTERNAL ENVIRONMENT WAS CALCULATED IN TERMS OF:

GAMMA RAY AND FAST NEUTRON DOSE RATES ON A MERIDIAN RING WITH A RADIUS OF 30 FEET

HEATING RATES AT THE ACTUATOR

TOTAL PROPELLANT TANK HEATING

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NUCLEAR AND RADIATION ENVIRONMENT DRAWING (981D523), SHEET 1

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HIGH SPECIFIC IMPULSE START UP AND SHUT DOWN

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NUCLEAR DATA

I MAJOR NUCLEAR PARAMETERS

- 1—NOMINAL CONTROL DRUM SPAN = $\$ 7.0 \pm 0.5$ (2σ).
 2—NOMINAL REACTIVITY SPAN IN SUPPORT STEMS = $\$ 1.0 \pm 0.25$ (2σ).
 3—ORIFICE ANGLE = 115 DEGREES.
 4—DRY K_{eff} PRIOR TO POISON WIRE REMOVAL ≈ 0.55 .

II CRITICAL CONTROL DRUM ANGLES* (UNCERTAINTIES ARE 2σ VALUES):

POWER TEST IDENTIFICATION	FULL POWER OPERATING TIME, SECONDS	COLD START-OF-LIFE A	HOT START-OF-LIFE D	HOT END-OF-LIFE E	COLD END-OF-LIFE G	COOLDOWN & SPACE STORAGE G-BB
INITIAL POWER RUN	3000	$111^\circ \pm 20^\circ$	$106^\circ \pm 18^\circ$	$124^\circ \pm 18^\circ$	$129^\circ \pm 20^\circ$	$129^\circ \pm 20^\circ$
1 ST RESTART		$^\circ \pm ^\circ$	$^\circ \pm ^\circ$	$^\circ \pm ^\circ$	$^\circ \pm ^\circ$	$^\circ \pm ^\circ$

* THIS TABLE IS APPLICABLE TO BOTH THE HIGH THRUST STARTUP, HIGH SPECIFIC IMPULSE SHUTDOWN AND THE HIGH SPECIFIC IMPULSE STARTUP AND SHUTDOWN CASE.

III POWER DISTRIBUTION (UNCERTAINTIES ARE 2σ VALUES):

POWER TEST IDENTIFICATION	HOT START-OF-LIFE				HOT END-OF-LIFE			
	D				E			
	MAX POWER FACTOR IN CORE	MIN. POWER FACTOR IN CORE	MAX. PERIPHERAL POWER FACTOR	MIN. PERIPHERAL POWER FACTOR	MAX. POWER FACTOR IN CORE	MIN. POWER FACTOR IN CORE	MAX. PERIPHERAL POWER FACTOR	MIN. PERIPHERAL POWER FACTOR
INITIAL POWER RUN	1.10 ± 0.10	0.6 ± 0.06	1.0 ± 0.10	0.6 ± 0.06	1.10 ± 0.10	0.7 ± 0.07	1.10 ± 0.10	0.7 ± 0.07
1 ST RESTART	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$

NUCLEAR AND RADIATION ENVIRONMENT DRAWING (981D523), Sheet 4

Table 1
 RADIATION ENVIRONMENT
 HIGH SPECIFIC IMPULSE START UP AND SHUT DOWN (FOR 1st CYCLE)

LOCATION See Sheet 1	PARAMETER	Transient		Transient		Transient		Start-of-Life		End-of-Life		Transient		Transient	
		A		B		C		D		E		F		G	
		Nominal	Uncertainty Factor	Nominal	Uncertainty Factor	Nominal	Uncertainty Factor	Nominal	Uncertainty Factor	Nominal	Uncertainty Factor	Nominal	Uncertainty Factor	Nominal	Uncertainty Factor
2	BTU/IN ³ /HR (Stem)									48000					
	BTU/IN/HR (Liner)									45000					
	NEUTRON/CM ² , E > 1.0 MEV									2.2(19)					
	NEUTRON/CM ² , E < 0.4 EV									4.2(17)					
	GAMMA RAY DOSE, ERGS/GM-C									4.4(12)					
11	BTU/IN ³ /HR (Stem)									16000					
	BTU/IN ³ /HR (Liner)									15000					
	NEUTRON/CM ² , E > 1.0 MEV									6.8(18)					
	NEUTRON/CM ² , E < 0.4 MEV									4.0(18)					
	GAMMA RAY DOSE, ERGS/GM-C									1.5(12)					

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SUMMARY OF REACTOR NUCLEAR AND RADIATION DISCUSSION

PERFORMANCE REQUIREMENTS AS LISTED IN THE NSS-CEI

CRITICAL CONTROL DRUM POSITIONS

COLD TO HOT REACTIVITY FEEDBACK

HOT POWER DISTRIBUTION

RADIAL POWER DISTRIBUTION DURING LIFE

UTILIZATION OF SUPPORT STEM REACTIVITY CONTROL

INTERNAL AND EXTERNAL RADIATION ENVIRONMENT

NUCLEAR AND RADIATION ENVIRONMENT DRAWING (981D523)

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REACTOR THERMAL AND FLUID FLOW PERFORMANCE REQUIREMENTS AND CHARACTERISTICS

OUTLINE

SUMMARY OF NSS - CEI THERMAL AND FLUID FLOW PERFORMANCE REQUIREMENTS

THERMAL AND FLUID FLOW ENVIRONMENT DRAWING (981D520)

SUMMARY OF THERMAL AND FLUID FLOW CHARACTERISTICS

STEADY STATE CHARACTERISTICS

TRANSIENTS CHARACTERISTICS

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REACTOR THERMAL AND FLUID FLOW PERFORMANCE
REQUIREMENTS FROM NSS-CEI (CP-677555)

<u>ITEM</u>	<u>REQUIREMENTS</u>	
3.1.1.1.1	DESIGN CONDITIONS	THRUST CHAMBER MIXED MEAN GAS TEMPERATURE 4500°R THRUST CHAMBER PRESSURE 450 PSIA FLOW RATE 88.7 LB/SEC
3.1.1.1.2	ENDURANCE	THE NSS SHALL HAVE AN ENDURANCE CAPABILITY OF 3000 SECONDS AT DESIGN CONDITIONS 4500 SECONDS AT DESIGN CONDITIONS FOR GROUND TEST ONLY
3.1.1.1.3	NUMBER OF STARTS	THE NSS SHALL BE CAPABLE OF TEN STARTS TO DESIGN CONDITIONS
3.1.1.1.4	STARTUP	INCREASE IN REACTOR POWER PRIOR TO FLOW INITIATION 200 SECONDS BOOTSTRAP TO CHAMBER TEMPERATURE OF 1000°R AND CHAMBER PRESSURE OF 60 PSIA SPECIFIED BY AGC MODE 1: RAMP TO DESIGN CHAMBER TEMPERATURE 23 SECONDS RAMP TO DESIGN CHAMBER PRESSURE 10 PSI/SEC MODE 2: RAMP TO DESIGN CHAMBER TEMPERATURE AND PRESSURE 23 SECONDS
3.1.1.1.5	SHUTDOWN	RAMP THAT DECREASE CHAMBER PRESSURE TO A POINT CONSISTENT WITH NSS LIMITATIONS WHILE MAINTAINING THE CHAMBER TEMPERATURE OF 4500°R - 10 PSI/SEC ROTATE CONTROL DRUMS TO THEIR MOST POISONED POSITION AND DECREASE CHAMBER TEMPERATURE TO 1500°R 20 SECONDS

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THERMAL AND FLUID ENVIRONMENT DRAWING (981D520), SHEET 2

HIGH SPECIFIC: IMPULSE STARTUP AND HIGH SPECIFIC IMPULSE SHUTDOWN

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THERMAL AND FLUID ENVIRONMENT DRAWING (981D520), SHEET 1

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TABLE 1
HIGH SPECIFIC IMPULSE START UP AND HIGH SPECIFIC IMPULSE SHUTDOWN AND COOLDOWN

LOCATION SEE SHEET 1	PARAMETER	INITIATION OF FLOW		INITIATION OF CHAMBER TEMP. RAMP		DESIGN CHAMBER TEMPERATURE AND PART PWR		DESIGN CHAMBER TEMP. AND FLOW, START OF LIFE		DESIGN CHAMBER TEMP. AND FLOW, END OF LIFE		DESIGN CHAMBER TEMPERATURE AND PART PWR		TERMINATION OF POWER	
		A		B		C		D		E		F		G	
		NOM	2 σ VARIATION	NOM	2 σ VARIATION	NOM	2 σ VARIATION	NOM	2 σ VARIATION	NOM	2 σ VARIATION	NOM	2 σ VARIATION	NOM	2 σ VARIATION
1	W - LB/SEC	1.2		22.1		42.1		67.5		67.0		40.9		30.4	
	P - PSIA	14		149		425		703		703		431		309	
	T - °R	556		66		188		193		193		211		213	
14	W - LB/SEC	.3		1.8		6.7		5.3		14.3		7.7		5.5	
	P - PSIA	24		167		546		740		854		552		403	
	T - °R	545		52		51		60		60		51		54	
15	W - LB/SEC	.3		1.8		6.7		5.3		14.3		7.7		5.5	
	P - PSIA	22		158		526		737		846		533		387	
	T - °R	629		792		455		530		160		327		385	
16	W - LB/SEC	.3		1.8		6.7		5.3		14.3		7.7		5.5	
	P - PSIA	12		120		390		643		644		393		281	
	T - °R	549		432		599		970		460		507		511	

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SUMMARY OF THERMAL AND FLUID FLOW CHARACTERISTICS

OUTLINE

HIGH IMPULSE STARTUP

HIGH IMPULSE SHUTDOWN

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HIGH IMPULSE STARTUP
PROFILE

LETTERS ("A","B","C") REFER TO POINTS
ON DRAWING 981D520 SHEET 2

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HIGH IMPULSE STARTUP
SUPPORT STEM MAXIMUM TEMPERATURES

LETTERS ("A", "B", "C") REFER TO POINTS
ON DRAWING 981D520 SHEET 2

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Astronuclear
Laboratory

HIGH IMPLUSE SHUTDOWN
SUPPORT STEM MAXIMUM TEMPERATURES

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REACTOR THERMAL AND FLUID FLOW PERFORMANCE
REQUIREMENTS AND CHARACTERISTICS

THE THERMAL AND FLUID FLOW PERFORMANCE REQUIREMENTS
HAVE BEEN PRESENTED

PRELIMINARY THERMAL PERFORMANCE REACTOR DATA FOR
HIGH IMPULSE STARTUP, STEADY STATE, AND SHUTDOWN IS
PRESENTED IN THE THERMAL AND FLUID ENVIRONMENT
DRAWING 981D520

PRELIMINARY THERMAL AND FLUID FLOW CHARACTERISTICS
HAVE BEEN PRESENTED

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

KEY REQUIREMENTS OF ECC

<u>ITEM</u>	<u>REQUIREMENT</u>
1. LOAD TRANSMITTAL	GROUP THE FUEL ELEMENTS INTO CLUSTERS AND TRANSMIT THE STATIC AND DYNAMIC LOADS TO THE SUPPORT PLATE.
2. REACTIVITY SHIMMING	PROVIDE FOR REACTIVITY SHIMMING AT ASSEMBLY.
3. INSULATION	PROVIDE A THERMAL BARRIER FOR PROTECTION OF METALLIC COMPONENTS.
4. SCREENING AND METERING	SCREEN AND METER THE FLOW TO EACH FUEL ELEMENT CHANNEL TO CONTROL TEMPERATURE DISTRIBUTION.
5. POISON WIRE ACCEPTANCE	INSURE ACCEPTANCE OF POISON WIRES AS REQUIRED FOR SAFETY.
6. EMERGENCY SUPPORT	PROVIDE I-g AXIAL SUPPORT FOLLOWING A LOSS-OF- COOLANT ACCIDENT.
7. RELIABILITY	RELIABILITY GOAL OF NOT LESS THAN 0.99990 RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

ALTERNATE DESIGN CONCEPTS

DESIGNATION

DESCRIPTION

REFERENCE DESIGN - COLD SECONDARY SUPPORT,
CONTACTING AFT END

COLD END SECONDARY SUPPORT WITH
CONTACTING AFT END HARDWARE AS
SHOWN ON LAYOUT 939J519

ALTERNATE DESIGN - COLD SECONDARY SUPPORT
STANDOFF AFT END

COLD END SECONDARY SUPPORT WITH
STANDOFF FROM AFT END HARDWARE
AS SHOWN ON LAYOUT 939J508
(MAIN VIEW)

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE REFERENCE DESIGN

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

CLUSTER SUPPORT LOAD PATHS FOR REFERENCE DESIGN (AFT END CONTACTING HARDWARE)

PRIMARY LOAD PATH

SECONDARY LOAD PATH

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE CLUSTER GROUPING

CORE TOTALS

TIE TUBES	349
FUELED ELEMENTS	1878
PARTIAL ELEMENTS	NONE
LARGEST STRIP AVG	.94
SMALLEST STRIP AVG	.20
REGULAR CLUSTERS	253
IRREGULAR CLUSTERS	48
TOTAL CLUSTERS	301

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE ALTERNATE DESIGN

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

CLUSTER SUPPORT LOAD PATHS FOR ALTERNATE DESIGN (STANDOFF FROM AFT END HARDWARE)

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RESTRICTED DATA
Atomic Energy Act - 1954

PRIMARY LOAD PATH

SECONDARY LOAD PATH

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

OUTLINE OF ANALYSIS

- A. CONCEPTUAL STRESS ANALYSIS
 - 1. CENTRAL ELEMENT STRESSES AND DEFLECTIONS
 - 2. SECONDARY SUPPORT STRESSES
- B. PRELIMINARY THERMAL AND HYDRAULIC ANALYSES
 - 1. CENTRAL ELEMENT TEMPERATURES
 - 2. INSULATING SLEEVE TEMPERATURES
- C. PRELIMINARY NUCLEAR ANALYSIS
 - 1. CENTRAL ELEMENT REACTIVITY SHIMMING WORTH
- D. PRELIMINARY RADIATION ANALYSIS
 - 1. POISON PLATE FLUX SUPPRESSION

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

PRELIMINARY CENTRAL ELEMENT STRESS SUMMARY

CONTACTING AFT END HARDWARE (REFERENCE)

MAXIMUM CENTRAL ELEMENT
AXIAL SHRINKAGE RELATIVE TO
FUEL ELEMENT DURING STARTUP
DUE TO THERMAL LAG (NO
FRICTION)

0.0125 IN. (XE-1 100°R/SEC STARTUP)
0.0088 IN. (XE-1 50°R/SEC HIGH IMPULSE
STARTUP)
0.0094 IN. (XE-1 50°R/SEC HIGH THRUST
STARTUP)

MAXIMUM CENTRAL ELEMENT
AXIAL DIRECT TENSILE STRESS
DURING STARTUP DUE TO THERMAL
LAG (NO SLIPPAGE, NO COMPRESSIVE
LOAD)

1200 PSI (XE-1 100°R/SEC STARTUP)
720 PSI (XE-1 50°R/SEC HIGH IMPULSE STARTUP)
450 PSI (XE-1 50°R/SEC HIGH THRUST STARTUP)

CENTRAL ELEMENT STEADY STATE
COMPRESSIVE LOAD (NO FRICTION)

-310 PSI (170 PSI CORE ΔP)

STANDOFF FROM AFT END HARDWARE (ALTERNATE)

MAXIMUM CENTRAL ELEMENT AXIAL
SHRINKAGE AND DIRECT TENSILE
STRESS NEGLECTING STANDOFF
INDUCED COMPRESSION

SAME AS ABOVE

CENTRAL ELEMENT STEADY STATE
COMPRESSIVE LOAD (NO FRICTION)

-2115 PSI (170 PSI CORE ΔP)

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE ELEMENT STRESSES IN STANDOFF FROM AFT END HARDWARE DESIGN

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE CENTRAL ELEMENT CREEP FOR NO FRICTION WITH STANDOFF DESIGN

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

SECONDARY SUPPORT CONCEPT PRELIMINARY STRESSES

MAXIMUM OPERATING LOAD PER ELEMENT	~ 100 LBS.
<u>TAB PLATE SUPPORT</u>	
TAB SHEAR	6,320 PSI
TAB BENDING	~ 120,000 PSI
ANCHOR TUBE TENSION	18,315 PSI
<u>FORKED KEY SUPPORT</u>	
ELEMENT SLOT BEARING	11,250 PSI
KEY HANGER TENSION	50,000 PSI
MAXIMUM OPERATING LOAD PER CLUSTER	~ 970 LBS.
SUPPORT TUBE TENSION	38,000 PSI
MAXIMUM LOSS OF COOLANT ACCIDENT LOAD PER ELEMENT	~ 10 LBS.

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE CENTRAL ELEMENT TEMPERATURE

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE
INSULATING SLEEVE TEMPERATURE
(FULL LENGTH METAL INSERT IN STEM)

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

AMBIENT CORE REACTIVITY SHIM MARGIN FOR VARIOUS NUMBERS
OF SHIM AND UNFUELED ELEMENT INTERCHANGES

CORE CONFIGURATION	NUMBER OF ELEMENTS INTERCHANGES	REACTIVITY* SHIM MARGIN
100 PERCENT OF ALL CENTRAL ELEMENTS AS T ₀ C SHIMS	349	8.70\$
ALL NON-INSTRUMENTED CENTRALS AS T ₀ C SHIMS REMAINDER AS REGULAR UNFUELED ELEMENTS	262	6.60\$
<hr/>		
REQUIREMENTS DUE TO UNCERTAINTIES IN REACTIVITY PREDICTIONS AND MANUFACTURING TOLERANCES	- - -	6.0\$ ⁺ 1.0\$

*BASED ON NERVA T₀C ELEMENT WORTHS NORMALIZED TO NRX-A6 EXPERIMENTAL
VALUES AND A 53 GRAM TOTAL AMOUNT OF T₀ PER ELEMENT

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

COMPARISON MATRIX OF DESIGN APPROACHES

<u>REQUIREMENTS OR FEATURES</u>	<u>REF. DESIGN - COLD SECONDARY SUPPORT, CONTACTING AFT END</u>	<u>ALT. DESIGN - COLD SECONDARY SUPPORT, STANDOFF AFT END</u>
NONSYMMETRICAL LOADING OF AFT END HARDWARE	HIGH	NONE
FUEL ELEMENT AND AFT END HARDWARE INTERACTION	HIGH (COMPATIBLE THERMAL EXPANSION REQUIRED)	NONE
CENTRAL ELEMENT STRESS	HIGH TENSILE (STARTUP)	LOW COMPRESSIVE
CENTRAL ELEMENT CREEP	LOW	MEDIUM (WEB THICKNESS MUST BE ADEQUATE FOR STRESS LEVEL. MORE CREEP DATA REQUIRED)
FUEL ELEMENT PRELOADING HARDWARE COMPLEXITY	MEDIUM	LOW
SECONDARY SUPPORT LOAD TRANSMITTAL	RELIES ON STRUCTURAL BRAZE	ALL MECHANICAL
SECONDARY SUPPORT STRESS	HIGH BENDING (TAB)	HIGH BEARING (ELEMENT SLOT)
FUEL ELEMENT MODIFICATION FOR SECONDARY SUPPORT	MINOR	EXTENSIVE

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

RECOMMENDED DESIGN APPROACH

THE COLD END SECONDARY SUPPORT WITH STANDOFF FROM AFT END HARDWARE, DRAWING NO. 939J508, WITH CONTINUED DEVELOPMENT OF THE SECONDARY SUPPORT SCHEME, IS RECOMMENDED FOR THE FOLLOWING REASONS:

1. MINIMIZES THE INTERACTION OF THE FUEL ELEMENTS WITH THE HOT END SUPPORT HARDWARE AND THUS MINIMIZES STRESSES ASSOCIATED WITH MULTIPLE RESTARTS.
2. PROVIDES SYMMETRICAL HOT END HARDWARE LOADING, THUS PERMITTING RELATIVE AXIAL EXPANSION OF THE FUEL ELEMENTS WITHOUT DETRIMENTAL EFFECT.
3. HAS BEST POTENTIAL OF MEETING ALL FUNCTIONAL AND TECHNICAL REQUIREMENTS.

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CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
LOAD TRANSMITTAL 3.1.1.1.1	VERIFY AXIAL LOAD CAPABILITY OF CENTRAL ELEMENT	EC 5.01	EC 5.01	EC 5.01
	VERIFY AXIAL STATIC AND DYNAMIC LOAD CAPABILITY OF STEM HOLDER	EC 5.02	EC 5.02	EC 5.02
	VERIFY DYNAMIC LOAD CAPABILITY OF COLD END HARDWARE	EC 5.03	EC 5.03	EC 5.03
CENTRAL ELEMENT REACTIVITY SHIMMING 3.1.1.1.2	VERIFY REACTIVITY WORTH OF CENTRAL ELEMENTS	W 1.1		W 1.1
	DETERMINE POWER DISTRIBUTIONS AND AFFECT OF CENTRAL ELEMENTS THEREON	W 3.1	W 3.1	
INSULATION 3.1.1.1.3	VERIFY INSULATING CAPABILITY OF CENTRAL ELEMENT AND INSULATING SLEEVES FOR VARIOUS STEM FLOW RATES	T 6.001	T 6.001	T 6.001
CLUSTER INTERSTITIAL CORROSION 3.1.1.1.4	INVESTIGATE ALLOWABLE INTERSTITIAL GAP SIZE FOR USE OF UNCOATED ELEMENTS	T 3.001		
	EVALUATE INTERSTITIAL CORROSION RATES	T 7.001		
NEUTRON FLUX SUPPRESSION 3.1.1.1.5	MEASURE REACTIVITY WORTH OF POISON PLATES	W 1.2	W 1.2	
	DETERMINE NEUTRON FLUX SUPPRESSION CAPABILITY OF POISON PLATES	W 3.2	W 3.2	

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
ELEMENT FLOW SCREENING 3.1.1.1.6	DETERMINE PRESSURE LOAD CARRYING CAPABILITY OF SCREEN UNDER PARTIAL BLOCKAGE	EC 5.04		
	DETERMINE FLOW IMPEDANCE CHARACTERISTICS OF SCREEN	T 6.002		
STEM FLOW PASSAGE 3.1.1.1.7	MEASURE SEAL LEAKAGE RATES OF CLUSTER ATTACHMENT HARDWARE	T 6.003	T 6.002	
FLOW METERING 3.1.1.1.8	MEASURE FUEL ELEMENT ORIFICE LOSS COEFFICIENT	T 6.004	T 6.003	
	DETERMINE ORIFICE BRAZE LEAKAGE RATES	T 6.005	T 6.004	
MALFUNCTIONS 3.1.1.1.11	VERIFY REDUNDANT CLUSTER SUPPORT AND PART RETENTION CAPABILITY UNDER STEM FAILURE	EC 5.05	EC 5.05	EC 5.05
	VERIFY STEM STRUCTURAL INTEGRITY CAPABILITY WITH A BROKEN FUEL ELEMENT	T 3.002	T 4.001	T 4.001
EMERGENCY SUPPORT 3.1.1.2.1	VERIFY SECONDARY SUPPORT LOAD CAPABILITY FOR LOSS OF COOLANT ACCIDENT	EC 5.06	EC 5.06	EC 5.06

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
OPERATING ENVIRONMENT 3.1.2.4.1	DETERMINE CLUSTER STRUCTURAL DEGRADATION IN VACUUM ENVIRONMENT	EC 6.01	EC 6.01	
	DETERMINE RADIATION ENVIRONMENT IN AND AROUND CLUSTER COMPONENTS	W 4	W 4	
TRANSPORTABILITY 3.1.2.5	VERIFY CAPABILITY OF CLUSTER ASSEMBLY TO WITHSTAND TRANSPORTATION SHOCK AND VIBRATION LOADS	EC 6.02	EC 6.02	EC 6.02
GENERAL DESIGN FEATURES 3.3.1	MEASURE REACTIVITY WORTH OF CLUSTER HARDWARE	W 1.3	W 1.3	
INSTRUMENTATION 3.3.1.3	VERIFY STRUCTURAL CAPABILITY OF CLUSTER COMPONENTS MODIFIED FOR INSTRUMENTATION	EC 6.03	EC 6.03	EC 6.03
	VERIFY THERMAL AND FLOW PERFORMANCE OF INSTRUMENTED CLUSTER ASSEMBLY	T 3.003	T 4.002	T 4.002
	INVESTIGATE EFFECTS OF INSTRUMENTATION ON CENTRAL ELEMENT THERMAL AND FLOW PERFORMANCE	T 7.002	T 7.001	
MOISTURE AND FUNGUS RESISTANCE 3.3.5	VERIFY MOISTURE AND FUNGUS RESISTANCE OF CLUSTER COMPONENTS	EC 9.01		EC 9.01

CLUSTER ASSEMBLY AND MISCELLANEOUS HARDWARE

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
CORROSION OF PARTS 3.3.6	VERIFY CAPABILITY OF CLUSTER MATERIALS TO WITHSTAND VARIOUS EXPECTED ENVIRONMENTS WITHOUT ADVERSE CORROSION	EC 9.02	EC 9.02	EC 9.02
	VERIFY HYDROGEN CORROSION RESISTANCE OF CLUSTER INTERNAL FLOW CHANNELS	T 3.004	T 4.003	T 4.003
	VERIFY HYDROGEN CORROSION RESISTANCE OF CLUSTER SURFACES	T 7.003	T 7.002	T 7.002
STORAGE 3.3.11	INVESTIGATE LONG TERM STORAGE ENVIRONMENT EFFECTS ON CLUSTER COMPONENTS	EC 9.03	EC 9.03	

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CONFIDENTIALCLUSTER HOT END SUPPORT HARDWAREALTERNATE DESIGN CONCEPTS

<u>DESIGNATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN	PEDESTAL SUPPORT WITH THE FUEL ELEMENT CONTACTING THE PEDESTAL. LAYOUT 939J519.
ALTERNATE NO. 1	PEDESTAL SUPPORT THROUGH THE CENTRAL ELEMENT WITH FUEL ELEMENT STANDOFF. LAYOUT 939J508.
ALTERNATE NO. 2	KEYED HOT END SUPPORT WITH GATHERED HOLE TIPPED FUEL ELEMENT CONTACTING THE SUPPORT. LAYOUT 939J543.
ALTERNATE NO. 3	KEYED HOT END SUPPORT THROUGH THE CENTRAL ELEMENT WITH GATHERED HOLE TIPPED FUEL ELEMENT STANDOFF. LAYOUT 939J541.

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CLUSTER HOT END SUPPORT HARDWARE PEDESTAL CONTACTING ELEMENTS

SECTION A-A

612480-5B

CLUSTER HOT END SUPPORT HARDWARE PEDESTAL WITH ELEMENT STANDOFF

612480-6B

AFT END INTERLOCK WITH CONTACTING ELEMENTS

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CLUSTER HOT END SUPPORT HARDWARE CLUSTER INTERLOCK PATTERN

612480-9B

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CLUSTER HOT END SUPPORT HARDWARE PEDESTAL WITH ELEMENT STANDOFF

612480-7B

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CLUSTER HOT END SUPPORT HARDWARE

ANALYSES OF DESIGN CONCEPTS

PRELIMINARY THERMAL AND HYDRAULIC ANALYSIS

1. BASIC ANALYTICAL MODELS
2. TABLE OF CALCULATED ΔT

PRELIMINARY STRESS ANALYSIS

1. PEDESTAL
2. PROTECTION CAP
3. PEDESTAL-TIP INTERACTION
4. GATHERED TIP

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CLUSTER HOT END SUPPORT HARDWARE

REFERENCE DESIGN ANALYTICAL MODEL

ALTERNATE DESIGNS ANALYTICAL MODEL

☞ GATHERED HOLE TIP

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CONFIDENTIALCLUSTER HOT END SUPPORT HARDWAREMAXIMUM ΔT DURING TRANSIENTS AND STEADY STATE CONDITIONS

		<u>REFERENCE DESIGN</u>		<u>ALTERNATE DESIGN - KEYED SUPPORT WITH GATHERED HOLE FUEL ELEMENT TIP</u>		
		<u>PEDESTAL</u>	<u>TRANSITION WASHER</u>	<u>EXTENDED PORTION OF CENTRAL ELEMENT</u>	<u>FUEL TIP AT GATHERED HOLE FROM FUEL-UNFUEL INTERFACE TO HOLE SURFACE</u>	
					STA. 51.8"	STA. 51.45"
200°R/SEC STARTUP	RADIAL	510°R	430°R	870°R	540°R	495°R
	AXIAL	275°R	675°R	400°R	-	-
200°R/SEC SHUTDOWN	RADIAL	310°R	MAXIMUM AT STEADY STATE	400°R	340°R	330°R
	AXIAL	230°R	140°R	460°R	-	-
STEADY STATE	RADIAL	155°R	270°R	150°R	40°R	40°R
	AXIAL	150°R	300°R	230°R	-	-

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CLUSTER HOT END SUPPORT HARDWARE

PEDESTAL AT 150°R/SEC STARTUP
970 LBS

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CLUSTER HOT END SUPPORT HARDWARE

PRELIMINARY ELASTIC CALCULATIONS-MAXIMUM STRESSES (AND STRAINS)

<u>LOAD CONDITIONS</u>	<u>BEARING DESIGN CLUSTER LOAD ON SIX FUEL ELE.</u>	<u>STANDOFF DESIGN CLUSTER LOAD ON CENTRAL ELE.</u>	<u>ESTIMATED ALLOWABLE*</u>
1. 970 POUND MAX. MECH. CLUSTER LOAD, NO TEMP GRADIENTS, 4300°R	2160 PSI (724 μ IN/IN)	650 PSI (220 μ IN/IN)	4350 PSI (5760 μ IN/IN)
2. +150°R/SEC STARTUP PLUS 970 POUND LOAD	5030 PSI** (1260 μ IN/IN)	5020 PSI** (1255 μ IN/IN)	4250 PSI (4640 μ IN/IN)
3. FULL POWER STEADY STATE PLUS 970 POUND LOAD	2450 PSI** (875 μ IN/IN)	1220 PSI** (440 μ IN/IN)	4400 PSI (5900 μ IN/IN)
4. SCRAM SHUTDOWN PLUS 970 POUND LOAD	3015 PSI** (655 μ IN/IN)	2310 PSI** (502 μ IN/IN)	4200 PSI (4160 μ IN/IN)

*.8 X .8 X (σ ULT) AVG.

**BASED ON STRAIGHT LINE STRESS-STRAIN CURVE

CLUSTER HOT END SUPPORT HARDWARE
PROTECTION CAP

SHELL MODEL

FINITE ELEMENT MODEL

STEADY STATE MAXIMUM ELASTICALLY
CALCULATED THERMAL STRAIN

MINIMUM ALLOWABLE PERMANENT
ELONGATION AT 30,000 PSI AND
3000°R

1800 μ IN/IN

7000 μ IN/IN

CLUSTER HOT END SUPPORT HARDWARE

TIP BENDING

STARTUP	± 1070	± 2680
BONDED (SHUTDOWN AFTER SLIPPING)	± 4060	± 5450
MIN. EXPECTED JOINT STRENGTH	± 2500	± 2000

CONDITIONS:

FRICTION COEFFICIENT = 1.0
 AXIAL LOAD/ELEMENT = 100 LBS
 FLEXURE LENGTH = 1.0 IN
 RELATIVE DEFLECTION = 3.6 MILS

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CLUSTER HOT END SUPPORT HARDWARE COMPARISON OF CTE DATA

612480-12B

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CLUSTER HOT END SUPPORT HARDWARE

COMPOSITE CREEP DEFORMATION

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CLUSTER HOT END SUPPORT HARDWARE

FINITE ELEMENT ANALYTICAL MODELS AND CALCULATED STRESS

LOAD CONDITIONS	CENTRAL ELEMENT		FUEL TIP	ALLOWABLE
	CONTACTING	STANDOFF		
200°R/SEC + 970 LB. LOAD	25,600 PSI 2320 μ IN/IN A	26,200 PSI 2450 μ IN/IN A	7,700 PSI 1375 μ IN/IN C	4250 PSI 5760 μ IN/IN
STEADY STATE + 970 LB. LOAD	4700 PSI 1510 μ IN/IN B	1000 PSI 296 μ IN/IN B	460 PSI 104 μ IN/IN D	4400 PSI 5900 μ IN/IN

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CLUSTER HOT END SUPPORT HARDWARE
COMPARISON MATRIX OF DESIGN APPROACHES

REQUIREMENTS OR FEATURES	REF. DESIGN PEDESTAL, CON- TACTING ELEM. (939J519)	ALT. NO. 1 PEDESTAL, STANDOFF (939J508)	ALT. NO. 2 GATHERED HOLE, CONTACTING ELEM. (939J543)	ALT. NO. 3 GATHERED HOLE, STANDOFF (939J541)
POSSIBLE ECCENTRIC LOAD ON CENTRAL	HIGH AFFECTS JOINT	VERY LOW	HIGH AFFECTS JOINT	VERY LOW
POSSIBLE FUEL TIP BEND. OR COATING DEGRAD.	HIGH	VERY LOW	HIGH	VERY LOW
PROBABLE OPENING OF HYDROGEN LEAK	HIGH	VERY LOW	MEDIUM	VERY LOW
MFG. COMPLEXITY	MEDIUM PRESENT ART	MEDIUM PRESENT ART	VERY HIGH REQ. DEVEL.	VERY HIGH REQ. DEVEL.
LEVEL OF ANALYTICAL EFFORT	HIGH PED., FUEL, & TIPS	MEDIUM CENT. EL.	VERY HIGH ALL COMPON.	HIGH CENT. EL. & TIP
MAX. COMPOS. THERMAL STRESS LEVEL	MEDIUM PED. I.D.	MEDIUM PED. I.D.	VERY HIGH SUPPT. FILLET	HIGH SUPPT. FILLET
STEADY STATE STRESS LEVEL	LOW	LOW	MEDIUM	MEDIUM
ADVERSE EFFECT OF USING TIPLESS FUEL	VERY HIGH COATING TRANS.	VERY LOW	VERY HIGH FUEL MFG.	VERY HIGH FUEL MFG.

CLUSTER HOT END SUPPORT HARDWARE

RECOMMENDED DESIGN APPROACH

THE PEDESTAL SUPPORT WITH FUEL ELEMENT STANDOFF (DWG. NO. 939J508) AND A BACKUP OF THE GATHERED HOLE TIPS WITH ELEMENT STANDOFF (DWG. NO. 939J541) ARE RECOMMENDED.

THE REASONS FOR THE RECOMMENDATION OF THE PEDESTAL SUPPORT WITH FUEL ELEMENT STANDOFF ARE AS FOLLOWS:

1. ELIMINATES THE FUEL TIP-SUPPORT INTERACTION AND COATING DEGRADATION THUS REDUCING THE STRESSES AND PROBLEMS ASSOCIATED WITH HIGH TEMPERATURE CREEP IN THE FUEL ELEMENTS.
2. RESULTS IN UNIFORM LOADING OF THE HOT END SUPPORT HARDWARE.
3. PROVIDES HOT END SUPPORT REDUNDANCY.
4. BECAUSE OF THE SIMPLICITY OF THE LOAD PATH, A RELIABLE BRAZED JOINT CAN BE ACHIEVED BETWEEN THE CENTRAL ELEMENT TIP, PEDESTAL, AND SUPPORT WASHER, WHICH WILL ELIMINATE POSSIBLE HYDROGEN LEAKAGE INTO THE PYROLYTIC GRAPHITE REGION AND OTHER KEY STRUCTURAL AREAS, SUCH AS THE PYROFOIL WASHER.
5. HAS THE BEST POTENTIAL OF MEETING ALL OF THE TECHNICAL AND FUNCTIONAL DESIGN REQUIREMENTS.

THE REASON FOR RECOMMENDING THE GATHERED HOLE TIPS WITH ELEMENT STANDOFF (DWG. NO. 939J541) AS A BACKUP IS THE SAME AS INDICATED ABOVE, PLUS THE FACT THAT SOME REDUNDANCY MAY BE PROVIDED BY KEYING THE ELEMENTS AND CLUSTERS TOGETHER AT THE AFT END. THIS IS NOT RECOMMENDED AS THE PRIMARY DESIGN BECAUSE OF THE UNCERTAINTIES AND COMPLICATIONS IN FUEL FABRICATION AND INSPECTION.

CLUSTER HOT END SUPPORT HARDWARE

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
LOAD SUPPORT 3.1.1.1.1	STRUCTURAL MARGIN AT ROOM AND ELEVATED TEMPERATURES, THERMAL SHOCK, SPACE ENVIRONMENT SIMULATION, AND AS CORRODED	EC 1.03 EC 2.02 EC 3.01 EC 3.04	EC 1.03 EC 2.02 EC 3.01 EC 3.04	EC 1.03 EC 2.02
	STRUCTURAL CAPABILITY AT SIMULATED REACTOR CONDITIONS	T 3.001	T 4.001	T 4.001
FLOW CHARACTERISTICS 3.1.1.1.2	DETERMINE VARIATION IN ORIFICED FUEL CHANNEL FLOW DUE TO INTERFACING PART	T 3.002	T 4.002	T 4.002
INSULATION 3.1.1.1.3	CAPABILITY OF INSULATION TO PROTECT SUPPORT STEM ASSEMBLY	EC 3.07 T 3.003	T 4.003	T 4.003
CLUSTER PARTS & FUEL INTERACTION 3.1.1.1.4	CREEP ENDURANCE CAPABILITY AND CYCLIC TEMPERATURE RUNS AT CONSTANT LOAD IN BOTH INERT GAS AND HYDROGEN ENVIRONMENT	EC 1.01 EC 1.04 T 3.004	EC 1.01 EC 1.04 T 4.004	EC 1.01 EC 1.04 T 4.004
MALFUNCTIONS 3.1.1.1.5	PARTS RETENTION CAPABILITY AT VARIOUS FAILURE CONDITIONS	EC 3.08 T 3.005	EC 3.08 T 4.005	EC 3.08 T 4.005
NON-OPERATING ENVIRONMENT 3.1.2.4.1.2	FLUX AND RADIATION DOSE DISTRIBUTIONS AND EFFECT OF CHESH THEREON	W 4	W 4	

CLUSTER HOT END SUPPORT HARDWARE

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
TRANSPORTABILITY 3.1.2.5	CAPABILITY TO WITHSTAND SHOCKS AND LOADS IMPOSED BY TRANSPORTATION MEDIA	EC 3.03	EC 3.03	EC 3.03
GENERAL DESIGN FEATURES 3.3.1	REACTIVITY WORTH OF CHESH POWER DISTRIBUTIONS AND EFFECT OF CHESH	W 1 W 3	W 1 W 3	
INSTRUMENTATION 3.3.1.3	CAPABILITY TO FUNCTION WHEN MODIFIED FOR INSTRUMENTATION	EC 3.09	EC 3.09 T 4.006	EC 3.09 T 4.006
MOISTURE AND FUNGUS RESISTANCE 3.3.5	CAPABILITY TO RESIST MOISTURE AND FUNGI UNDER CONDITIONS FAVORABLE TO FUNGI DEVELOPMENT	EC 9.01		EC 9.01
CORROSION OF PARTS 3.3.6	CAPABILITY TO WITHSTAND NSS CORROSION ENVIRONMENTS	EC 9.02 T 3.006	EC 9.02 T 4.007	EC 9.02 T 4.007
STORAGE 3.3.11	DEMONSTRATE NO ADVERSE EFFECTS DUE TO STORAGE PRIOR TO NSS USAGE	EC 9.03	EC 9.03	

CLUSTER HOT END SUPPORT HARDWARE

SUMMARY OF PRESENTATION

1. FOUR CONFIGURATIONS HAVE BEEN DESIGNED AND EVALUATED TO MEET ALL THE ECC REQUIREMENTS.
2. PRELIMINARY CALCULATED STRAINS IN COMPOSITE MATERIALS ARE WELL WITHIN THE MATERIAL LIMITATIONS.
3. STEADY STATE THERMAL ANALYSIS SHOWS ALL CONFIGURATIONS ACCEPTABLE.
4. THE PEDESTAL WITH ELEMENT STANDOFF DESIGN APPROACH HAS BEEN RECOMMENDED WITH THE GATHERED HOLE TIP WITH ELEMENT STANDOFF DESIGN AS A BACKUP, BOTH BASED ON THE COMPARISON MATRIX PRESENTED.
5. THE TEST VERIFICATION PROGRAM HAS BEEN SUMMARIZED TO CONVEY THE SCOPE OF THE TEST PROGRAM PLANNED FOR THE QUALIFICATION OF THE CHESH AS A PART OF THE NSS.

SUPPORT STEM ASSEMBLY KEY REQUIREMENTS OF ECC

	<u>ITEM</u>	<u>REQUIREMENT</u>
3.1.1.1.1	CORE SUPPORT	CAPABILITY FOR CARRYING CORE LOADS DURING REACTOR OPERATION
3.1.1.1.2	FLUID PASSAGE AND CONTAINMENT	PROVISION FOR PASSING HYDROGEN COOLANT IN A TWO-PASS MANNER THROUGH THE STEM ASSEMBLIES.
3.1.1.1.3	REACTIVITY ADJUSTMENT	CONTAINMENT OF SUFFICIENT HYDROGEN TO PERMIT CORE REACTIVITY ADJUSTMENT BY THROTTLING THE INLET FLOW.
3.1.2.1	RELIABILITY	RELIABILITY GOAL OF NOT LESS THAN 0.99990 RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE

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SUPPORT STEM ASSEMBLY
ALTERNATE DESIGN CONCEPTS

<u>DESIGNATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN	DRAWN TUBE WITH STRAIGHT-THROUGH I. D. AND THREADED ENDS AS SHOWN ON LAYOUT 939J508 (MAIN VIEW).
ALTERNATE NO. 1	SWAGED TUBE WITH THREADED ENDS AS SHOWN ON LAYOUT 939J508 (SHOWN AS OPTIONAL DESIGN VIEW).
ALTERNATE NO. 2	DRAWN TUBES WITH BRAZED END CONNECTIONS AS SHOWN ON LASL DRAWING 43Y65213E1.
ALTERNATE No. 3	SHIMMING SLEEVE WITH REMOVABLE CLOSURE CAP AS SHOWN ON LAYOUT 914E130. (LOWER VIEW)

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SWAGED STEM ASSEMBLY

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STEM ASSEMBLY USING STRAIGHT (UNSWAGED) STEM

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STEM ASSEMBLY USING STRAIGHT (UNSWAGED) STEM

612480-23D

IN-PLACE SHIMMING CONCEPT

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SUPPORT STEM ASSEMBLY OUTLINE OF ANALYSIS

RADIATION

NUCLEAR

THERMAL AND FLUID FLOW

STRUCTURAL

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SUPPORT STEM ASSEMBLY

RADIATION ENVIRONMENT SUMMARY

COMPONENT	MAXIMUM RADIATION LEVEL					MAXIMUM HEATING RATE
	GAMMA DOSE RATE	NEUTRON FLUX (N/CM ² -SEC)		FLUENCE* (NVT)		BTU/HR-IN ³ -MATERIAL
	ERGS/GM-C-HR	E > 1.0 MEV	E < 0.4 EV	E > 1.0 MEV	E < 0.4 EV	
SUPPORT STEM	3.5 (12)	4.9 (15)	8.8 (14)	2.2 (19)	4.0 (18)	4.8 (4) (INCONEL)
LINER TUBE	3.5 (12)	4.9 (15)	8.8 (14)	2.2 (19)	4.0 (18)	4.5 (4) (STEEL)
ORIFICING HARDWARE	4.9 (11)	6.1 (14)	6.0 (13)	2.7 (18)	2.7 (17)	6.3 (3) (STEEL)

NOTE: * FOR 75 MINUTE FULL POWER RUN

+ NUMBERS IN PARENTHESES REFER TO POWERS OF TEN

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SUPPORT STEM ASSEMBLY
IN-PLACE SHIMMING

MANUFACTURING TOLERANCES	<u>+</u> \$1.50
COLD CRITICAL UNCERTAINTY	<u>+</u> \$0.75 (2 σ)
IN-PLACE SHIMS	<u>+</u> \$1.50

BENEFITS

REDUCES OPERATING DRUM ANGLE UNCERTAINTY

REDUCES CONTROL DRUM SPAN REQUIREMENT BY \$1.5

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SUPPORT STEM ASSEMBLY
NUCLEAR ANALYSIS SUMMARY

IN CORE REACTIVITY COEFFICIENTS

INCONEL	- 1.21¢/kg
STAINLESS STEEL	- 0.24¢/kg
HYDROGEN	+5.39\$ /kg

POWER PERTURBATIONS

FUEL ELEMENT ADJACENT TO STEM CONTAINING 0.81 gm H₂ (MAX. FLOW)

ELEMENT - CENTRAL INTERFACE +1%

ELEMENT - ELEMENT INTERFACE > -1%

CORE POWER FACTOR CHANGE

SS REACTIVITY INSERTION	CENTER LINE	PERIPHERY
\$1	0.7% INCREASE	0.9% DECREASE
\$2	1.4% INCREASE	1.8% DECREASE

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SUPPORT STEM ASSEMBLY

THERMAL AND FLUID FLOW ANALYSIS SUMMARY

SUPPORT STEM ASSEMBLY

INCONEL 718
ESTIMATED MINIMUM ELONGATION

125

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SUPPORT STEM ASSEMBLY
STRESS ANALYSIS SUMMARY

STEM				LINER			CLOSURE CAP		
PRIMARY LOADS	CONTROLLING PARAMETERS	LOAD LBS	STRESS PSI	PRIMARY LOADS	CONTROLLING PARAMETERS	STRESS PSI	PRIMARY LOADS	CONTROLLING PARAMETERS	STRESS PSI
CORE ΔP	170 PSID	623	44,500	PRESSURE	390 PSID	5200	PRESSURE	390 PSID	9000
WEIGHT	12 LBS	12	900						
			45,400						
SECONDARY LOADS				SECONDARY LOADS			SECONDARY LOADS		
AXIAL PRELOAD SPRING FRICTION	70 LBS 8 PSI BUNDLING 0.1 COEFF. OF FRICTION	70 15	5,000 1,100	BENDING	0.060 INCH	3750	THERMAL DISPLACEMENT	3.27 MILS	31500
SUPPORT PLATE BOW	0.049 INCH	108	7,600						
STEM TEMPERATURE VARIATION	100°R	134	9,600						
BENDING	0.060 INCH		5,000						
			28,300						
COMBINED			73,700			6350			40500
ALLOWABLE PRIMARY STRESS			98,000			9600			14,800
PRIMARY MARGIN OF SAFETY	116%				85%			65%	
ALLOWABLE COMBINED STRESS			240,000 (1.5 σ_u)			26000 (2 σ_y)			20,000 (2 σ_y)
COMBINED MARGIN OF SAFETY	220%				300%			0%	

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SUPPORT STEM ASSEMBLY

COMPARISON MATRIX OF DESIGN APPROACHES

REQUIREMENTS OR FEATURES	REFERENCE DESIGN- STRAIGHT THRU STEM (939J508, MAIN VIEW)	ALT. NO. 1 - SWAGED STEM (939J508, OPTIONAL VIEW)	ALT. NO. 2-LASL BRAZED CONCEPT (43Y65213E1)	ALT. NO. 3 - IN-PLACE SHIMMING SCHEME (914E130)
MANUFACTURING	SIMPLE	COMPLEX	SIMPLE	COMPLEX
FORWARD END ATTACHMENT	COMPLEX	SIMPLE	SIMPLE	COMPLEX
MEANS OF SUPPORT	RELIABLE (THREADED CONNECTION)	RELIABLE (THREADED CONNECTION)	LESS RELIABLE (BRAZED JOINTS)	RELIABLE (THREADED CONNECTION)
THERMAL SAFETY MARGIN	HIGH	HIGH	LOW (BRAZE LIMITATION)	LOW (LEAKAGE UNCERTAINTY)
HYDROGEN CON- TAINMENT	GOOD	GOOD	GOOD	FAIR (AFT END HDW)
ORIFICE LOCATION	EXIT FIRST PASS ONLY	EXIT FIRST OR EXIT SECOND PASS	EXIT FIRST OR EXIT SECOND PASS	EXIT FIRST PASS ONLY
SOL REACTIVITY UNCERTAINTIES	+\$1	+\$1	+\$1	+0.25
CONTROL DRUM SPAN REQUIREMENTS	\$7.0	\$7.0	\$7.0	\$5.5

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SUPPORT STEM ASSEMBLY RECOMMENDED DESIGN APPROACH

THE STRAIGHT-THROUGH STEM (DRAWING NO. 939J508 MAIN VIEW) IS RECOMMENDED FOR THE FOLLOWING REASONS:

SIMPLICITY OF MANUFACTURE, SINCE ALTERNATE FABRICATION TECHNIQUES CAN BE READILY EMPLOYED AND NO BRAZING IS REQUIRED.

THREADED CONNECTIONS INHERENTLY PROVIDE MORE RELIABLE MEANS OF AXIAL CORE SUPPORT THAN BRAZE JOINTS.

IT READILY PROVIDES A LEAK-PROOF TWO-PASS FLOW ARRANGEMENT AND HYDROGEN CONTAINMENT.

PROVIDES INHERENT RELIABILITY BECAUSE OF THE SIMPLICITY OF DESIGN AND MANUFACTURE.

HAS BEST POTENTIAL OF MEETING ALL FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS.

SUPPORT STEM ASSEMBLY (SSA)
TEST SUMMARY

<u>ECC REQUIREMENTS</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
CORE SUPPORT 3.1.1.1.1	LOAD TEST UNDER REACTOR CONDITIONS	T 3.001	T 4.001	T 4.001
	STRENGTH TEST	EL 1.01	EL 1.02	EL 1.04
	DEFLECTION TEST	EL 1.02	EL 1.04	
	DYNAMICS TEST	EL 1.04		
FLUID PASSAGE & CONTAINMENT 3.1.1.1.2	LEAK TEST UNDER REACTOR CONDITIONS	T 3.002	T 4.002	T 4.002
	PRESSURE TEST	EL 1.03	EL 1.03	EL 1.03
	LEAKAGE TEST	EL 1.05	EL 1.05	
REACTIVITY ADJUSTMENT 3.1.1.1.3	WORTH OF SSA IN PAX/R-1 ASSEMBLY	W 2	W 2	
	POWER DISTRIBUTION AND EFFECTS OF SSA MATERIAL IN PAX/R-1 ASSEMBLY	W 3	W 3	
ORIFICING 3.1.1.1.4	SSA THERMAL TEST	T 3.003	T 4.003	T 4.003
	IMPEDANCE TEST	T 6.001	T 6.001	T 6.001
POSITIONING 3.1.1.1.5	AXIAL POSITION TEST	EL 2.05	EL 2.05	

SUPPORT STEM ASSEMBLY (SSA) (CONT.)

TEST SUMMARY

<u>ECC REQUIREMENTS</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
DEFLECTION 3.1.1.1.6	LATERAL POSITION TEST	EL 1.02	EL 1.02	EL 1.02
OPERATING ENVIRONMENT 3.1.2.4.1	NUCLEAR PARAMETER TEST	W 4	W 4	
TRANSPORTABILITY 3.1.2.5	VIBRATION TESTS	EL 2.08	EL 2.08	EL 2.08
GENERAL DESIGN FEATURES 3.3.1	WORTH OF SSA MATERIAL IN PAX/R-1 ASSEMBLY	W 1	W 1	
INSTRUMENTATION 3.3.1.3	PERFORMANCE TEST OF SSA	T 3.004	T 4.004	T 4.004
	STATIC TESTS	EL 2.06	EL 2.06	EL 2.06
	DYNAMIC TESTS	EL 2.07	EL 2.07	EL 2.07
MOISTURE & FUNGUS RESISTANCE 3.3.5	RESISTANCE TEST	EL 9.01		EL 9.01
CORROSION OF PARTS 3.3.6	ENVIRONMENT TEST	EL 9.02	EL 9.02	EL 9.02
		T 3.005	T 4.005	
STORAGE 3.3.11	ENVIRONMENT TEST	EL 9.03	EL 9.03	

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SUMMARY OF SUPPORT STEM ASSEMBLY DISCUSSION

REQUIREMENTS - CORE SUPPORT, FLUID PASSAGE AND CONTAINMENT, REACTIVITY
ADJUSTMENT, AND RELIABILITY

DESIGN CONCEPTS - FOUR (4) APPROACHES

ANALYSIS - HYDROGEN REACTIVITY SWING \$1 TO \$2 ADEQUATE MARGINS OF
SAFETY

COMPARISON MATRIX

RECOMMENDED DESIGN APPROACH - STRAIGHT-THROUGH STEM

TEST SUMMARIES

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SUPPORT STEM FEED AND DISCHARGE SYSTEM
FUNCTIONAL AND TECHNICAL REQUIREMENTS

1. FLOW CHARACTERISTICS AND FLUID CONTAINMENT (3.1.1.1.1 AND 3.1.1.1.2)
DUCT HYDROGEN IN THE SUPPORT STEM FEED PIPING SYSTEM, THE SUPPORT STEM FEED PLENUM, THE BYPASS PIPING SYSTEM, AND THE MIXING CHAMBER TO MEET REQUIREMENTS.
2. LEAKAGE (3.1.1.1.3)
PERMIT A LEAKAGE OF NOT GREATER THAN 1 LB/SEC IN THE FEED PIPING AND FEED PLENUM WITH A MAXIMUM LEAKAGE OF 0.002 LB/SEC AT ANY JOINT.
3. AXIAL FLOW PASSAGES (3.1.1.1.4)
PROVIDE AXIAL FLOW PASSAGES TO CHANNEL ALL THE REACTOR COOLANT FLOW TO THE CORE SUPPORT PLATE.
4. LOAD TRANSMITTAL (3.1.1.1.5)
CARRY SUPPORT STEM LOADS (CORE PRESSURE DROP) INTO THE CORE SUPPORT PLATE.
5. FLEXIBILITY (3.1.1.1.6)
PROVIDE FLEXIBILITY FOR THERMAL EXPANSIONS AND FIT UP VARIATIONS BETWEEN THE PRESSURE VESSEL DOME AND THE FEED PLENUM AND MIXING CHAMBER.
6. SCREENING (3.1.1.1.7)
SCREEN FLOW TO THE SUPPORT STEM INLET.
7. TEMPERATURE VARIATION (3.1.1.1.8)
DISTRIBUTE THE FLOW TO THE SUPPORT STEMS WITH A MAXIMUM TEMPERATURE VARIATION OF 12°R. PROVIDE THE EFFLUENT TO THE CORE SUPPORT PLATE WITH A MAXIMUM TEMPERATURE VARIATION OF 11°R.
8. RELIABILITY (3.1.2.1)
RELIABILITY GOAL OF NOT LESS THAN 0.99999 RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

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Astronuclear
Laboratory

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

DESCRIPTION OF DESIGN CONCEPTS

<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN - CENTRAL FEED BYPASS	CENTER FEED BYPASS AS SHOWN ON LAYOUT 939J509
ALTERNATE NO. 1 - PERIPHERAL FEED BYPASS	PERIPHERAL FEED BYPASS AS SHOWN ON LAYOUT 939J542
ALTERNATE NO. 2 - COMBINED SUPPORT PLATE AND PLENA	COMBINED SUPPORT PLATE AND PLENUM FEED AS SHOWN ON DRAWING 939J521

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS) REFERENCE DESIGN CENTER FEED BYPASS (939J509)

612528-1B

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS) REFERENCE DESIGN CENTER FEED BYPASS (939J509)

612528-2B

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

REFERENCE DESIGN CENTER FEED BYPASS (939J509)

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

ALTERNATE NO. 1 PERIPHERAL FEED BYPASS (939J542)

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

COMBINED SUPPORT PLATE AND PLENA (939J521)

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

COMBINED SUPPORT PLATE AND PLENA (939J521)

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)
COMBINED SUPPORT PLATE AND PLENA (939J521)

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS) COMBINED SUPPORT PLATE AND PLENA (939J521)

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

OUTLINE OF ANALYSIS

- A. CONCEPTUAL STRESS ANALYSIS
 - 1. PLENA PLATE
 - 2. SUPPORT PLATE
 - 3. COMBINED SUPPORT PLATE AND PLENA
- B. PRELIMINARY THERMAL AND HYDRAULIC ANALYSES
 - 1. SEAL LEAKAGE
 - 2. SUPPORT STEM FEED EFFLUENT AND BYPASS MIXING
 - 3. TEMPERATURE VARIATION, CORE INLET
- C. AMBIENT REACTIVITY WORTHS

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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

DISCUSSION OF ANALYSIS RESULTS

A. CONCEPTUAL STRESS ANALYSIS

1. PLENA PLATE, REFERENCE DESIGN AND ALTERNATE NO. 1

RESULTS FROM "PLATES" PROGRAM:

1. THICK PLATE TENDS TO KEEP PRESSURE LOAD STRESSES LOW
2. THIN PLATE TENDS TO KEEP DISPLACEMENT STRESSES LOW
3. LOWER STRESSES IN CENTRAL REGION
4. STRESSES SENSITIVE TO SPOOL LENGTHS
5. STRESSES SENSITIVE TO BOUNDARY CONDITIONS
6. 0.06 INCH PLENA PLATE STRESSES

<u>BOUNDARY CONDITIONS</u>	<u>PRESSURE LOADING</u>		<u>BOUNDARY DISPLACEMENT</u>	<u>MATERIAL ALLOWABLE 2219T87 AL. AT 200°R</u>
	<u>CENTRAL REGION</u>	<u>PERIPHERAL REGION</u>	<u>CENTRAL REGION</u>	
CLAMPED SUPPORT	11,000 PSI	43,500 PSI	21,200 PSI	51,000 PSI
SIMPLE SUPPORT	5,000 PSI	29,500 PSI	2,200 PSI	

2. SUPPORT PLATE, REFERENCE DESIGN AND ALTERNATE NO. 1

MAXIMUM DEFLECTION = 0.049 IN.	MAXIMUM STRESS = 13,850 PSI	MINIMUM YIELD = 46,000 PSI
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3. COMBINED SUPPORT PLATE AND PLENA, ALTERNATE NO. 2

MAXIMUM DEFLECTION = 0.057 IN. (NRX-A6 = 0.070 IN.)	MAXIMUM STRESS = 15,860 PSI (NRX-A6 = 15,600 PSI)	MINIMUM YIELD = 46,000 PSI
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SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

PRELIMINARY THERMAL AND HYDRAULIC ANALYSES LEAKAGE PATHS INVOLVED IN LOCAL LEAKAGE

REFERENCE DESIGN AND
ALTERNATE NO. 1

ALTERNATE NO. 2

612430-36B

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)
DISCUSSION OF ANALYSIS RESULTS

B. PRELIMINARY THERMAL AND HYDRAULIC ANALYSIS

1. SEAL LEAKAGE

REFERENCE DESIGN AND ALTERNATE NO. 1 HAVE SEALS ($552 \times 2 = 1104$) AROUND AXIAL FLOW PASSAGES. ALTERNATE NO. 2 REQUIRED NO SEALS FOR AXIAL PASSAGES.

2. STEM EFFLUENT AND BYPASS MIXING

REFERENCE DESIGN AND ALTERNATE NO. 2 HAVE MIXING CHAMBER EFFLUENT FROM 4 TO 40°R ABOVE EXTENSION SHIELD OUTLET GAS TEMPERATURE. ALTERNATE NO. 1 HAS BYPASS (60°R), STEM EFFLUENT (300 TO 800°R), AND EXTENSION SHIELD (277°R) GAS STREAM MIXING.

3. TEMPERATURE VARIATION, CORE INLET

REFERENCE DESIGN AND ALTERNATE NO. 2 A STATISTICAL COMBINATION OF AZIMUTHAL VARIATIONS (30°R MIXING CHAMBER, 12°R EXTENSION SHIELD) INDICATE THAT THE REQUIREMENT OF 11°R MAXIMUM TEMPERATURE VARIATION AT CORE INLET CAN BE MET.

ALTERNATE NO. 1, DUE TO PERIPHERAL MIXING, COULD BE MORE DIFFICULT TO MEET THE 11°R REQUIREMENT.

C. AMBIENT REACTIVITY WORTH

REFERENCE CONFIGURATION (939J300) ALL SSFDS COMPONENTS HAVE NEGLIGIBLE EFFECT ON THE CORE NEUTRONICS.

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

COMPARISON MATRIX OF DESIGN APPROACHES

<u>REQUIREMENTS OR FEATURES</u>	<u>REFERENCE DESIGN - CENTRAL FEED BYPASS (939J509)</u>	<u>ALTERNATE NO. 1 PERIPHERAL FEED BYPASS (939J542)</u>	<u>ALTERNATE NO. 2 COMBINED SUPPORT PLATE AND PLENA (939J521)</u>
LEAKAGE - GROSS	MEDIUM (2151 SEALS)	MEDIUM (2151 SEALS)	LOW (1049 SEALS)
LOCAL	MEDIUM	MEDIUM	LOW
TEMPERATURE VARIATION, CORE INLET	MEDIUM	HIGH	MEDIUM
MACHINING COMPLEXITY	MEDIUM	MEDIUM	VERY HIGH
NEW TECHNOLOGY REQUIREMENT	LOW	LOW	MEDIUM
TEMPERATURE VARIATION, MIXING CHAMBER	MEDIUM	VERY HIGH	MEDIUM
NUMBER OF PARTS	VERY HIGH (3536)	VERY HIGH (3512)	VERY LOW (424)
DIFFICULTY OF ASSEMBLY	HIGH	HIGH	LOW
STRESS SENSITIVITY TO DISPLACEMENTS	VERY HIGH	VERY HIGH	VERY LOW
NSS WEIGHT (LENGTH)	MEDIUM (SSFDS 860 LBS)	MEDIUM (SSFDS 830 LBS)	LOW (SSFDS 530 LBS)

SUPPORT STEM FEED AND DISCHARGE SYSTEM

RECOMMENDED DESIGN APPROACH

IT IS RECOMMENDED THAT THE SUPPORT STEM FEED AND DISCHARGE SYSTEM BE ALTERNATE NO. 2, WHICH COMBINES THE SUPPORT STEM FEED AND DISCHARGE SYSTEM WITH THE SUPPORT PLATE, SHOWN IN DRAWING 939J521, FOR THE FOLLOWING REASONS:

1. HAS THE BEST POTENTIAL OF MEETING ALL THE TECHNICAL AND FUNCTIONAL REQUIREMENTS.
2. THE DESIGN PROVIDES THE LOWEST OVERALL REACTOR LENGTH.
3. PROVIDES BEST MIXING OF STEM FLOW AND BYPASS AND MINIMIZES THE POTENTIAL LEAKS.
4. THE BASIC SIMPLICITY OF THE DESIGN WILL PROVIDE FOR INHERENT RELIABILITY.

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
FUNCTIONAL CHARACTERISTICS (3.1.1)	REACTIVITY WORTHS OF SSFDS MATERIALS AND NUCLEAR MOCK-UPS.	W1	W1	
	LOCAL POWER PERTURBATIONS DUE TO SSFDS MATERIALS AND NUCLEAR MOCK-UPS.	W3	W3	
FLOW CHARACTERISTICS & FLUID CONTAINMENT (3.1.1.1.1 & 3.1.1.1.2) AXIAL FLOW PASSAGES (3.1.1.1.4)	FLOW IMPEDANCE OF PASSAGES FOR SSFDS DESIGNS. REACTOR OPERATING CONDITIONS.	T6.001 (3.1.1.1.1 & 3.1.1.1.2)	T6.001	T6.001
		T6.003	T6.003 (3.1.1.1.4)	T6.003
FLUID CONTAINMENT (3.1.1.1.2) FLEXIBILITY (3.1.1.1.6)	EVALUATE FLUID CONTAINMENT CAPABILITY OF DESIGNS FOR THERMAL AND MECHANICAL MOTIONS OF ASSEMBLY AND CYCLIC OPERATION.	EF 2.01	EF 2.01	EF 2.01
LEAKAGE (3.1.1.1.3)	EVALUATE SSFDS SEAL DESIGNS FOR DIMENSIONS, FINISHES, AND OPERATING CONDITIONS.	T6.002	T6.002	T6.002
LOAD TRANSMITTAL (3.1.1.1.5)	EVALUATE CAPABILITY OF STEM HOLDER/CLUSTER NUT/PLENUM PLATE DESIGNS FOR ASSEMBLY AND OPERATING LOADS.	EF 1.01	EF 1.01	EF 1.01

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
LOAD TRANSMITTAL (3.1.1.1.5) TRANSPORTABILITY (3.1.2.5)	DETERMINE VIBRATION/TRANSPORTATION CAPABILITY OF SSFDS DESIGNS. OPERATING, NONOPERATING ENVIRONMENTS.	EF 3.02	EF 3.02	EF 3.02
TEMPERATURE VARIATION (3.1.1.1.8)	MEASURE VARIATIONS AT PERIPHERY FOR FLOW MODELS. MIXING OF TWO HYDROGEN FLOWS.	T 6.004		
OPERATING ENVIRONMENT (3.1.2.4.1)	MEASUREMENTS AROUND PRELIMINARY AND NUCLEAR MOCK-UPS.	W4	W4	
INSTRUMENTATION (3.3.1.3)	FLOW IMPEDANCE VARIATION DUE TO INSTRUMENTATION APPLICATION. REACTOR OPERATING CONDITIONS.	T 6.005	T 6.004	T 6.004
	DEVELOP AND VERIFY THAT DESIGNS HAVE NOT BEEN DEGRADED DUE TO INSTRUMENTATION.	EF 1.01	EF 1.01	EF 1.01

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
MOISTURE & FUNGUS RESISTANCE (3.3.5)	DETERMINE RESISTANCE OF MATERIALS AND HARDWARE. MIL-STD-810A, METHOD 508.	EF 9.01		EF 9.01
CORROSION OF PARTS (3.3.6)	DEVELOP DATA FOR MATERIALS AND HARD- WARE FOR SPECIFIED LOCATION ENVIRON- MENTS.	EF 9.02	EF 9.02	EF 9.02
STORAGE (3.3.11)	DEVELOP DATA FOR MATERIALS AND HARD- WARE FOR SPECIFIED STORAGE REQUIRE- MENTS.	EF 9.03	EF 9.03	EF 9.03

SUPPORT STEM FEED AND DISCHARGE SYSTEM (SSFDS)

SUMMARY OF PRESENTATION

1. COMBINED SUPPORT PLATE AND PLENA (ALTERNATE NO. 2) IS THE MORE SIMPLE AND STRAIGHT FORWARD DESIGN APPROACH.
2. REFERENCE DESIGN AND ALTERNATE NO. 1 PLENA PLATE STRESSES ARE VERY SENSITIVE TO SPOOL LENGTHS. COMBINED SUPPORT PLATE AND PLENA (ALTERNATE NO. 2) STRESSES ARE LOW AND CLOSE TO THE NRX-A6 VALUES.
3. REFERENCE DESIGN AND ALTERNATE NO. 2 MIXING CHAMBER EFFLUENT TEMPERATURE IS CLOSE TO THE EXTENSION SHIELD OUTLET. ALTERNATE NO. 1 HAS WIDE SPREAD IN MIXING STREAM TEMPERATURES. ALTERNATE NO. 2 HAS MINIMUM LEAKAGE.
4. SSFDS COMPONENTS HAVE NEGLIGIBLE EFFECTS ON CORE NEUTRONICS.
5. CONSIDERABLE DEVELOPMENT, PREQUALIFICATION, AND QUALIFICATION TESTING IS REQUIRED TO VERIFY THE SSFDS.

FUEL ELEMENTS

C. STRUCTURAL ANALYSIS

3. CONCEPT COMPARISONS (CONTINUED)

EXTERNAL COATING

- a. COATING OF AFT END ONLY OF ALL ELEMENTS
- b. COATING OF CENTRALS FULL LENGTH, AFT END OF FUEL ELEMENTS
- c. FULL LENGTH COATING ON ALL ELEMENTS

AGAIN, A CHOICE BETWEEN NbC AND ZrC IS NOT EVIDENT

TIP CONFIGURATION

FOR THIS ORDERING IT IS ASSUMED THAT EITHER THE FUEL ELEMENT IS NOT CONTACTING THE PEDESTAL (STANDOFF DESIGN) OR THAT THE PEDESTAL EXPANSION HAS BEEN MATCHED TO THE FUEL, ELIMINATING THE QUESTION OF THE BENDING OF THE TIP DUE TO DIFFERENTIAL EXPANSION OF THE PEDESTAL RELATIVE TO THE FUEL.

HIGH EXPANSION ELEMENT

- a. NO TIP
- b. 1.0 INCH COMPOSITE TIP
- c. 1.0 INCH COMPOSITE AND TRANSITION TIP

LOW EXPANSION ELEMENT

- a. 1.0 INCH REDUCED CTE COMPOSITE AND TRANSITION TIP
- b. 1.0 INCH REDUCED CTE COMPOSITE TIP

FUEL ELEMENTS

C. STRUCTURAL ANALYSIS

3. CONCEPT COMPARISONS

PRESENT ANALYSIS AND EXPERIENCE INDICATE THE FOLLOWING STRUCTURAL ORDERING OF FUEL ELEMENT CONCEPTS:

MATRIX AND BORE COATING

- a. HIGH EXPANSION MATRIX WITH GEM COATING (ALTERNATE 3)*
- b. LOW EXPANSION, NO ADDITIVE MATRIX, GED + MOLY COATING (REFERENCE DESIGN)
- c. LOW EXPANSION, MATRIX ADDITIVES, GED + MOLY COATING (ALTERNATE 2)
- d. LOW EXPANSION WITH GEM COATING (REFERENCE DESIGN)

*THE FIRST POSITION OF THE HIGH EXPANSION FUEL ELEMENT IS BASED ON POTENTIAL ONLY. IT IS STILL IN THE PRELIMINARY DEVELOPMENT PHASE AND HAS NOT HAD ITS CAPABILITY PROVEN.

THERE IS NOT ENOUGH INFORMATION AVAILABLE TO CHOOSE BETWEEN NbC AND ZrC COATINGS (ALTERNATE 1) FROM A STRUCTURAL STANDPOINT AT THIS TIME.

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C. STRUCTURAL ANALYSIS

STRESS
MECHANISM
INTERACTION WITH
CORE PERIPHERY

CAUSE
COOLANT FLOW
LEAKAGE AXIALLY
AT CORE PERIPHERY

FUEL ELEMENTS

MAGNITUDE IN
REFERENCE DESIGN
DEPENDS ON
PERIPHERY
DESIGN

<u>EFFECT OF ALTERNATES</u>		
<u>1</u>	<u>2</u>	<u>3</u>
<u>ZrC</u>	<u>ADDITIVE</u>	<u>HIGH EXPANSION</u>
NO CHANGE	NO CHANGE	INCREASED BY 80%

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FUEL ELEMENTS

C. STRUCTURAL ANALYSIS

EFFECT OF ALTERNATES

<u>STRESS MECHANISM</u>	<u>CAUSE</u>	<u>MAGNITUDE IN REFERENCE DESIGN</u>	<u>1</u> <u>ZrC</u>	<u>2</u> <u>ADDITIVE</u>	<u>3</u> <u>HIGH EXPANSION</u>
STRESS DUE TO INTER-ACTION WITH UN-FUELED MATERIALS	DIFFERENCE IN AVERAGE TEMPERATURE BETWEEN FUEL ELEMENT AND UNFUELED ELEMENTS ESPECIALLY DURING TRANSIENTS	LESS THAN 600 PSI	NO CHANGE	NO CHANGE	INCREASED BY 80%
BUNDLING PRESSURE STRESSES	LATERAL BUNDLING PRESSURE ON FUEL ELEMENTS	SMALL (<200 PSI)	NO CHANGE	NO CHANGE	NO CHANGE
AXIAL PRESSURE DROP STRESS	PRESSURE DROP LOAD	-240 PSI CONTACTING DESIGN 74 PSI STANDOFF DESIGN, NO FRICTION	NO CHANGE	NO CHANGE	NO CHANGE
STRESS AT FUEL AXIAL SUPPORT	TRANSFER OF FUEL PRESSURE DROP LOAD TO SUPPORT HARDWARE	DEPENDS ON CONFIGURATION	NO CHANGE	NO CHANGE	NO CHANGE
FUEL BEND STRESS AT CORE PERIPHERY	BENDING OF ELEMENTS TO FOLLOW CORE RADIAL GROWTH PROFILE	440 PSI	NO CHANGE	NO CHANGE	TO ABOUT 800 PSI

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FUEL ELEMENTS

C. STRUCTURAL ANALYSIS

EFFECT OF ALTERNATES

<u>STRESS MECHANISM</u>	<u>CAUSE</u>	<u>MAGNITUDE IN REFERENCE DESIGN</u>	<u>1 ZrC</u>	<u>2 ADDITIVE</u>	<u>3 HIGH EXPANSION</u>
FUEL BEAD-MATRIX INTERACTION	LARGER EXPANSION OF FUEL BEAD THAN MATRIX	2200 PSI AT BEAD-MATRIX INTERFACE	NO CHANGE	NO CHANGE	REDUCED INTERACTION
COATING-MATRIX INTERACTION	DIFFERENTIAL EXPANSION BETWEEN MATRIX AND COATING	GED - 1650 PSI AT 4500°R GEM - 4050 PSI AT 4500°R	EFFECT UN- KNOWN AT THIS TIME	NO CHANGE	REDUCES INTERACTIONS
ORIFICE-MATRIX INTERACTION	DIFFERENTIAL EXPANSION BETWEEN ORIFICE AND MATRIX	DEPENDS UPON SELECTED ORIFICE MATERIAL	NO CHANGE	NO CHANGE	REDUCED INTERACTION
TIP-MATRIX INTERACTION	DIFFERENTIAL EXPANSION BETWEEN TIP MATERIALS AND MATRIX	18,200-20,000 WITH HIGH EXPANSION 75-25 COMPOSITE	NO CHANGE	NO CHANGE	REDUCED INTERACTION
THERMAL STRESSES DUE TO POWER GENERATION	HEAT FLOW FROM FUEL BEADS IN MATRIX INTO COOLANT HOLES	860 PSI MAXIMUM	NO CHANGE	NO CHANGE	INCREASED TO ABOUT 1550 PSI
FUEL AXIAL STRESS DUE TO DIFFERENTIAL AXIAL EXPANSIONS	VARIATIONS IN AVERAGE TEMPERATURE AND EXPANSION COEFFICIENT FROM ELEMENT TO ELEMENT	1360 PSI (3σ)	NO CHANGE	NO CHANGE	INCREASES TO 1700 PSI WITH NO EXTERNAL COATING

FUEL ELEMENTS

C. STRUCTURAL ANALYSIS

2. STRESS MECHANISMS

- a. FUEL BEAD - MATRIX INTERACTION
- b. COATING - MATRIX INTERACTION
- c. ORIFICE - MATRIX INTERACTION
- d. TIP - MATRIX INTERACTION
- e. THERMAL STRESSES DUE TO POWER GENERATION
- f. STRESS DUE TO FUEL DIFFERENTIAL AXIAL EXPANSIONS
- g. STRESS DUE TO INTERACTION WITH UNFUELED MATERIALS (ESPECIALLY DURING TRANSIENTS)
- h. BUNDLING PRESSURE STRESSES
- i. STRESSES DUE TO AXIAL PRESSURE DROP
- j. STRESSES AT AXIAL SUPPORT
- k. BENDING OF ELEMENTS AT CORE PERIPHERY
- l. STRESSES DUE TO INTERACTIONS WITH THE CORE PERIPHERY

FUEL ELEMENTS

C. STRUCTURAL ANALYSIS

1. STRUCTURAL REQUIREMENTS

THE FUEL ELEMENT HEATS THE HYDROGEN PROPELLANT TO THE REQUIRED TEMPERATURE. ITS ONLY STRUCTURAL REQUIREMENT IS THAT IT PERFORM THIS FUNCTION FOR THE REQUIRED TIME WITHOUT EXCESSIVE REACTIVITY LOSS AND WITHOUT THE EJECTION OF PIECES.

HOWEVER, TO MEET THIS REQUIREMENT IT IS NECESSARY TO MINIMIZE THE NUMBER OF POINTS AT WHICH HOT UNSATURATED HYDROGEN PROPELLANT CAN REACH UNPROTECTED GRAPHITE. IT IS THIS GRAPHITE PROTECTION REQUIREMENT WHICH MAKES THE PREVENTION OF FUEL ELEMENT CRACKING A STRUCTURAL REQUIREMENT.

THUS, THE PRIMARY REQUIREMENT OF STRUCTURAL ANALYSIS IN FUEL ELEMENT DEVELOPMENT IS TO MINIMIZE THE NUMBER AND SEVERITY OF CORROSION PRODUCING CRACKS. A SECONDARY REQUIREMENT IS TO KEEP THE FUEL ELEMENTS INTACT. ONLY IN A DESIGN IN WHICH THE FUEL ELEMENT IS A STRUCTURAL MEMBER WOULD THE REQUIREMENT OF INTACT ELEMENTS BE A PRIMARY REQUIREMENT. THIS IS NOT THE CASE IN ANY OF THE PRESENT NERVA ALTERNATES.

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FUEL ELEMENTS

- C. STRUCTURAL ANALYSIS
 - 1. STRUCTURAL REQUIREMENTS
 - 2. STRESS MECHANISMS
 - 3. CONCEPT COMPARISONS (STRUCTURAL)

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FUEL ELEMENTS

ALTERNATE 1 - LOW EXPANSION, LOW VOID, STANDARD MATRIX, ZrC COATING (711J550)
SIMILAR TO REFERENCE DESIGN EXCEPT SUBSTITUTE ZrC COATING FOR NbC COATING

ALTERNATE 2 - LOW EXPANSION, LOW VOID, NbC ADDITIVE MATRIX, NbC COATING (711J551)
SIMILAR TO REFERENCE DESIGN EXCEPT THE MATRIX INCLUDES 2.5 VOLUME PERCENT NbC PARTICLES
TO ENHANCE COATING ADHERANCE

ALTERNATE 3 - HIGH EXPANSION, LOW VOID, NO MATRIX ADDITIVE, NbC COATING (711J554)
SIMILAR TO REFERENCE DESIGN EXCEPT AS FOLLOWS:

1. MATRIX IS A HIGH EXPANSION GRAPHITE WHICH MORE NEARLY MATCHES THE THERMAL EXPANSION COEFFICIENT OF THE COATING (80% INCREASE OVER STANDARD MATRIX)
2. AFT TIP DESIGN CHANGED TO BE COMPATIBLE WITH HIGH EXPANSION MATRIX

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FUEL ELEMENTS

REFERENCE DESIGN - LOW EXPANSION, LOW VOID, STANDARD MATRIX AND NbC COATING

1. 0.753 NOMINAL HEXAGON
2. 19 FLOW CHANNELS, 27% VOID FRACTION AFTER COATING
3. 52 INCH OVERALL LENGTH
4. PYROLYTIC COATED URANIUM CARBIDE FUEL BEADS
5. GRAPHITE FLOUR, CARBON BLACK AND CATALYZED BINDER MATRIX
6. FUEL TRANSVERSE EXPANSION CONTROLLED TO BE LESS THAN 1.3%
7. BRAZED ORIFICES
8. BORE COATING
 - a. LOW TEMPERATURE VAPOR DEPOSITION PROCESS (GEM) WHICH DEPOSITS NbC FROM Nb and C (METHANE)
 - b. HIGH TEMPERATURE VAPOR DEPOSITION PROCESS (GED) WHICH DEPOSITS Nb AND OBTAINS C FROM MATRIX, FOLLOWED BY MOLYBDENUM COATING PROCESS
9. 2.50 INCHES AFT END EXTERNAL COATING
10. 1.0 INCH HOT END TIP WITH 0.44 INCH COMPOSITE AND 0.56 INCH GRAPHITE TRANSITION

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B. DESIGN CONCEPTS

<u>DESIGNATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN	A LOW EXPANSION MATRIX WITH NO ADDITIVE AND A NIOBIUM CARBIDE VAPOR-DEPOSITED CORROSION PROTECTION COATING (711J550)
ALTERNATE NO. 1	A ZIRCONIUM-CARBIDE VAPOR-DEPOSITED CORROSION PROTECTION COATING APPLIED TO STANDARD MATRIX TYPE (711J550)
ALTERNATE NO. 2	AN ADDITION OF NIOBIUM-CARBIDE PARTICLES TO THE LOW-EXPANSION MATRIX (711J551) (UNISSUED)
ALTERNATE NO. 3	A HIGH EXPANSION MATRIX WITH NO MATRIX ADDITIVE WITH NbC COATING (711J554) (UNISSUED)

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FUEL ELEMENTS

A. REQUIREMENTS

1. NUCLEAR CRITICALITY - AS A PART OF THE NSS SHALL BE CAPABLE OF SUSTAINING A CONTROLLED NUCLEAR FISSION REACTION
2. THERMAL AND FLOW CHARACTERISTICS - WITH ORIFICES SHALL BE CAPABLE OF MEETING ALL REQUIRED REACTOR OPERATING CONDITIONS
3. TEMPERATURE VARIATION - MINIMUM TEMPERATURE SHALL BE NOT MORE THAN 375°R BELOW AVERAGE TEMPERATURE OF SURROUNDINGS
4. RADIAL EXPANSION - CORE SHALL NOT EXPAND RADIALY MORE THAN 1.3%
5. CORROSION AND REACTIVITY LOSS - HYDROGEN CORROSION WEIGHT LOSS SHALL NOT EXCEED 14 GRAMS AVERAGE, 50 GRAMS MAXIMUM, AFTER 50 MINUTES OF DESIGN POINT OPERATION, INCLUDING TEN 5-MINUTE RUNS THIS CORRESPONDS TO \$1 REACTIVITY LOSS.
6. BUNDLING LOAD - SHALL BE CAPABLE OF WITHSTANDING THE MAXIMUM BUNDLING LOAD APPLIED BY THE CORE PERIPHERY (60 PSI)
7. TIP CONFIGURATION - SHALL HAVE A COMPOSITE-GRAPHITE TIP AT THE HOT END WHICH IS COMPATIBLE WITH THE CLUSTER HOT END SUPPORT HARDWARE
8. ELEMENT LEAKAGE - AS LEACHED BODY LEAKAGE SHALL NOT EXCEED 170 STANDARD CC/MIN. TIP JOINT LEAKAGE SHALL NOT EXCEED 68 STANDARD CC/MIN.
9. RELIABILITY GOAL - RELIABILITY SHALL BE NOT LESS THAN 0.99862 RELATIVE TO STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

FUEL ELEMENTS

- A. FUEL ELEMENT REQUIREMENTS
- B. DESIGN CONCEPTS
- C. DISCUSSION OF ANALYSIS RESULTS
 - STRUCTURAL
 - THERMAL AND FLUID FLOW
 - NUCLEAR
 - RADIATION
- D. COMPARISON MATRIX OF DESIGN CONCEPTS AND RECOMMENDED APPROACH
- E. TEST VERIFICATION REQUIREMENTS

FUEL ELEMENTS

DISCUSSION OF ANALYSIS RESULTS (CONTINUED)

THERMAL AND FLUID FLOW

REQUIREMENTS
TEMPERATURES
CORROSION AND REACTIVITY LOSS
FLOW CONTROL BENEFITS

NUCLEAR

REQUIREMENTS
LOADING
POWER DISTRIBUTION

RADIATION

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FUEL ELEMENT THERMAL REQUIREMENTS

	<u>NERVA</u>	<u>NRX-A6</u>
Nominal Power Per Element - KW	809	681
Maximum Power Per Element - KW	890	770
Nominal Flow Per Element - lb/sec	0.0468	0.0421
Maximum Flow Per Element - lb/sec	0.0513	0.0476
Nominal Exit Gas Temperature - °R	4550	4325
Core ΔP - psid	170	135
Number Specified Cycles	10	1
Full Power Operating Time	75 Min.	60 Min.

* Calculation based on 1878 fuel elements and core thermal power 1521 MW.

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AXIAL TEMPERATURE DISTRIBUTION WITH A 1.0 INCH
COMPOSITE-GRAPHITE TIP IN A CHANNEL WITH A POWER
FACTOR OF 1.1

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SUMMARY OF NRX-A6 AND NERVA HOT CHANNEL FACTORS

	Core Center, °R	Core Periphery, °R
<u>NRX-A6 ELEMENT HOT CHANNEL (3σ)</u>		
Error in Gamma and Neutron Heating: Magnitude and Distribution	104	69
Error in Uranium Assay of Fuel	48	95
Error in Fission Distribution and Cold-to-Hot Adjustment	59	218
Flow Distribution in Inlet Plenum	158	158
Temperature Distribution in Inlet Plenum	98	98
Effect of X-Coat on Flow Impedance	159	159
Combination of all Other Individual Channel Effects	92	92
NRX-A6 STATISTICAL TOTAL 3 SIGMA	293	362
<u>NERVA ELEMENT HOT CHANNEL⁺</u> (1.17 x NRX-A6)	424	(Total - 3 SIGMA)
	280	(Total - 2 SIGMA)

+ PRELIMINARY

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TABLE 6-5
NERVA CALCULATED STATISTICAL TEMPERATURES⁺

<u>NOMINAL TEMPERATURE (°R)</u>	<u>REFERENCE DESIGN</u>
FUEL ELEMENT EXIT GAS	4550
FUEL ELEMENT MATERIAL (CALCULATED BY MCAP PROG.)	4700
<u>TEMPERATURE UNCERTAINTIES (°R)⁺⁺</u>	
2σ HOT CHANNEL TEMPERATURE - DUE TO UNCERTAINTIES IN FUEL ELEMENT POWER AND FLOW	280
2σ VARIATION IN REACTOR OPERATING TEMPERATURE	100
STATISTICAL TOTAL (2σ)	300
<u>2σ MAXIMUM TEMPERATURES (°R)⁺</u>	
FUEL ELEMENT EXIT GAS	4850
FUEL ELEMENT MAXIMUM MATERIAL	5000

⁺TEMPERATURE INCREASE DUE TO CONTROL DRUM MOTION NOT INCLUDED

⁺⁺PRELIMINARY BASED ON EXTENDING NRX-A6 VALUES

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FUEL ELEMENT CORROSION ANALYSIS METHOD APPLIED FOR
PRELIMINARY NERVA CORROSION EVALUATIONS

LOWERE CODE COMPUTATIONAL METHOD FOR NRX-A6 QUALITY FUEL* WAS
APPLIED TO NERVA CALCULATIONS WITH THE FOLLOWING ADJUSTMENTS

1. MIDBAND WEIGHT LOSS ADJUSTED UP BY 22% TO ACCOUNT
FOR THE HIGHER NERVA FLOW RATE.
2. HOT END CORROSION EXPRESSION IN LOWERE
WAS EXTRAPOLATED TO THE NERVA TEMPERATURE LEVEL.
3. NO FUEL ELEMENT EXTERNAL CORROSION WAS INCLUDED.
THE OVERESTIMATE OF MIDBAND WEIGHT LOSS OBSERVED IN
NRX-A6 WAS CONSIDERED TO ACCOUNT FOR EXTERNAL
CORROSION.
4. NO ADDITIONAL CORROSION WAS INCLUDED TO ACCOUNT
FOR THE NERVA CYCLING REQUIREMENT.

* APPLICATION OF THIS CALCULATION METHOD TO NRX-A6 GIVES \$1.10
CORROSION REACTIVITY LOSS. MEASURED REACTIVITY LOSS WAS

\$0.85 + 0.32
- 0.20

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PRELIMINARY CALCULATED REACTIVITY LOSS VS. TIME

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WEIGHT LOSS - REACTIVITY RELATION

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TABLE 6-6

PRELIMINARY ANALYSIS SUMMARY
EFFECT OF SUPPORT STEM FLOW CONTROL ON FE

- I. SUMMARY OF SUPPORT STEM FLOW CONTROL ANALYSIS TO DATE
 1. MAXIMUM FUEL ELEMENT, MAXIMUM CLUSTER HOT END SUPPORT STRUCTURE, AND MAXIMUM CORE PERIPHERY TEMPERATURES ARE REDUCED APPROXIMATELY 60°F PER 1.0\$ OF SUPPORT STEM REACTIVITY
 2. CALCULATED HOT END FUEL ELEMENT CORROSION IN THE WORST REGION OF THE CORE IS REDUCED APPROXIMATELY 15% PER 1.0\$ OF SUPPORT STEM REACTIVITY.
 3. DECREASE IN CORE CORROSION REACTIVITY LOSS DUE TO FLOW CONTROL IS SMALL, BASED ON CALCULATIONS CONSIDERING BORE CORROSION ONLY
 4. FLOW CONTROL RESULTS IN A FLATTER RADIAL TEMPERATURE PROFILE IN THE CORE AND THEREBY MORE UNIFORM BUNDLING AND DECREASED INTERELEMENT CORROSION
- II. ANALYSIS OF SUPPORT STEM PERFORMANCE AND DESIGN TRADE-OFF ARE CONTINUING

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PRELIMINARY NERVA MULTIZONED FUEL DISTRIBUTION FOR THE REFERENCE
DESIGN WITH GED COATING PROCESS⁽¹⁾

FUEL LOADING CODE	URANIUM LOADING (MG/CC OF FUELED GRAPHITE)	TOTAL URANIUM (51.0 IN.) (GMS)	TOTAL CARBON (51.0 IN.) (GMS)	TOTAL NIOBIUM (51.0 IN.) (GMS)	TOTAL ⁽²⁾ MOLYBDENUM FOR CHANNEL COATING (GMS)
11	265	75.7	525.9	65	3.3
12	397	113.6	517.8	65	3.3
13	418	119.3	516.4	65	3.3
14	440	125.6	514.8	65	3.3
15	463	132.3	513.0	65	3.3
16	487	139.2	511.2	65	3.3
17	513	146.5	509.2	65	3.3
18	540	154.2	507.1	65	3.3
19	569	162.4	504.6	65	3.3
20	598	171.0	501.9	65	3.3
21	630	179.9	499.0	65	3.3
TOLERANCE		±2.5%	±2.0%	±5.0%	±1.0 GMS

⁽¹⁾ LOADINGS WERE CALCULATED TO GIVE APPROXIMATELY A 3.0\$ EXCESS REACTIVITY AT THE 111° COLD
CRITICAL DRUM POSITION.

⁽²⁾ AFTER ROOM TEMPERATURE BLOWDOWN

NERVA FUEL ELEMENT LOADING AND CONTROL DRUM SPAN

DESIGN	COATING PROCESS	LOADING RANGE (MG/CC)	CONTROL DRUM SPAN (DIFFERENCE FROM REF. DESIGN)
REFERENCE	GED	265 - 630	
NbC COATING	GEM	262 - 623	
ALTERNATE 1	GED	217 - 515	INCREASED \$ 0.60
ZrC COATING	GEM	214 - 510	
ALTERNATE 2	GED	302 - 718	DECREASED \$ 0.60
MATRIX ADDITIVE	GEM	299 - 710	
ALTERNATE 3			
HIGH EXPANSION MATRIX	GEM/GED	SAME AS REFERENCE	SPAN MUST BE INCREASED \$0.60 TO ACCOUNT FOR LESS REACTIVE HOT CORE OR REDUCTION IN REQUIREMENTS ACCEPTED

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RADIATION ANALYSIS

1. RADIATION ENVIRONMENT AND HEATING RATE FOR THE REFERENCE DESIGN FUEL ELEMENT HAVE BEEN CALCULATED
2. SIMILAR CALCULATIONS HAVE NOT BEEN MADE FOR THE ALTERNATE FUEL ELEMENT DESIGNS, HOWEVER QUALITATIVE ESTIMATES OF EXPECTED CHANGES IN THE RADIATION EMMITTED BY THE REACTOR HAVE BEEN MADE.

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(CRD) The comparison matrix of design approaches is given in the following two figures. The following comments apply to these VG's:

- 1) Reactor experience
- 2) Manufacturing experience
- 3) Corrosion and cyclic performance - Although the NbC GED process FE performed

well in the NRX-A6 reactor, electric furnace test results indicate that this FE will not be adequate to meet the NERVA cyclic requirements. The NbC GEM coating process FE has shown better cyclic performance in electric tests. However, it is less likely that this FE can be improved enough to meet NERVA requirements than either alternate 1 or alternate 3. The PEWEE-1 reactor test will give information on cyclic corrosion performance of these elements in a reactor.

(CRD) Alternate 1 (ZrC) has the potential to meet the NERVA requirements. LASL has furnace tested 34 ZrC and ZrC/NbC coated elements from 10 coating process experiments (Reference N-1-2196). Twenty-two of these elements had less than 6-1/2 grams corrosion weight loss in the three-cycle 60-minute test. This compares to corrosion losses of 10 to 14 grams for PEWEE-1 NbC coated elements in the same test. NbC GEM/ZrC GED combination coating elements are planned for PEWEE-2 as are ZrC experimental elements.

(CRD) Alternate 2 (Additive) has slightly better corrosion performance than the reference design. This slight corrosion advantage is not considered to be significant enough to warrant the nuclear disadvantages and increase tendency for hydrolysis. This element has been eliminated as a NERVA candidate.

(CRD) Alternate 3 (High Expansion) has the potential to meet NERVA requirements. WANL furnace tests of 28 elements have been made. Testing difficulties were encountered. However, six elements ran four 10-minute cycles at the high temperature R. 107 test and five elements ran five 10-minute cycles at a lower temperature D. 101 test. The results of these tests including metallography on four elements and examination of sectioned element photographs are promising. These results indicate good hot end cyclic performance. Cyclic effects are still evident in the midband region. Continued development is recommended.

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- (CRD)
- 1) Coating development
 - 2) Properties testing - Thermal and mechanical properties
 - 3) Component redesign - The radial expansion of high expansion matrix will require changes in the design of the core peripheral and lateral support region.
 - 4) Molybdenum overcoat required - The overcoat is a disadvantage, resulting in higher hot channel temperatures.
 - 5) Variation in CTE - Higher variation results in a less tightly bundled core and greater interelement corrosion.
 - 6) Uranium loading and CD span - Alternate 1 has a nuclear advantage and alternate 2 has a disadvantage.
 - 7) Stress considerations - The high expansion matrix and the GED coating process are favored. The thermal stress levels are acceptable for the standard matrix elements. Although the high expansion element has greater thermal stresses, the total stress is not greater than other designs (because of reduction in other stresses).

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COMPARISON MATRIX OF DESIGN APPROACHES-FUEL ELEMENTS

REQUIREMENTS OR FEATURES MATRIX COATING	REFERENCE DESIGN STANDARD NbC		ALTERNATE 1 STANDARD ZrC		ALTERNATE 2 ADDITIVE NbC		ALTERNATE 3 HIGH EXPANSION NbC		
	GED	GEM	GED	GEM	GED	GEM	GED	OR	GEM
REACTOR EXPERIENCE	YES	NO	NO	NO	LIMITED	NO	NO		
MANUFACTURING EXPERIENCE	NRX PW-1	PW-1	PILOT	NO	A6 EXP PW-1	PW-1	PILOT		
CORROSION AND CYCLIC PERFORMANCE	NOT ADEQUATE	BETTER CYCLIC	POTENTIAL		SLIGHT IMPROVEMENT OVER REFERENCE		POTENTIAL		
COATING DEVELOPMENT PROGRAM		NO	REQUIRED			NO	NO		
PROPERTIES TESTING REQUIRED		NO	YES			YES	YES		
COMPONENT REDESIGN REQUIRED		NO	NO			NO	YES		
MOLYBDENUM OVERCOAT REQUIRED	YES	MAY	YES	MAY	YES	MAY	NO		

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COMPARISON MATRIX OF DESIGN APPROACHES, FUEL ELEMENTS (CONT.)

REQUIREMENTS OR FEATURES MATRIX COATING	REFERENCE DESIGN STANDARD NbC		ALTERNATE 1 STANDARD ZrC		ALTERNATE 2 ADDITIVE NbC		ALTERNATE 3 HIGH EXPANSION NbC	
	GED	GEM	GED	GEM	GED	GEM	GED	GEM
	LOW	HIGHER	LOW	HIGHER	MEDIUM	HIGHER	HIGHER	
VARIATION IN CTE								
URANIUM LOADING	265-630 MG/CC		18% LOWER		14% HIGHER		SAME	
CONTROL DRUM SPAN	\$7.0		\$0.6 GREATER		\$0.60 LESS		SAME (REQUIRES \$0.60 MORE)	
FUEL - CENTRAL CTE COMPAT- IBILITY	GOOD	POOR	GOOD	POOR	GOOD	POOR	GOOD	
COAT - MATRIX INTERACTION STRESS	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	
ORIFICE-MATRIX INTERACTION, MATRIX-TIP INTER- ACTION STRESSES	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	REDUCED	
THERMAL STRESS	ACC	ACC	ACC	ACC	ACC	ACC	INCREASED BY 80%	

FUEL ELEMENTS

DESIGN RECOMMENDATION

THE RECOMMENDED FUEL ELEMENT IS A LOW EXPANSION STANDARD MATRIX ELEMENT. OF THE FE DESIGNS CONSIDERED, THE PRIME COATING CANDIDATE IS THE ZrC VAPOR DEPOSITED COATING OF ALTERNATE 1, WHILE THE NbC VAPOR DEPOSITED COATING OF THE REFERENCE DESIGN IS THE BACKUP COATING PROCESS. COMBINATION COATINGS OF ZrC AND NbC, SUCH AS THAT BEING DEVELOPED FOR PW-2 IS ALSO RECOGNIZED AS A COATING CANDIDATE. THIS RECOMMENDATION IS PRIMARILY BASED ON THE GREATER POTENTIAL OF ZrC TO MEET THE FUEL ELEMENT CORROSION REQUIREMENTS AND THE NUCLEAR ADVANTAGES OF ZrC. THE NbC PROCESS IS RETAINED AS A BACKUP UNTIL THE ZrC COATING PROCESS IS PROVEN.

IT IS ALSO RECOMMENDED THAT DEVELOPMENT EFFORT CONTINUE ON THE HIGH EXPANSION MATRIX ELEMENTS OF ALTERNATE 3. THIS RECOMMENDATION IS BASED ON THE STRESS ADVANTAGES, AND POTENTIAL CYCLIC CAPABILITY OF THIS ELEMENT. IF THE HIGH EXPANSION MATRIX ELEMENT PROVES TO BE REQUIRED TO ACHIEVE THE ENDURANCE AND CYCLIC OBJECTIVES, SOME REACTOR REDESIGN WILL BE REQUIRED, PRIMARILY IN THE PERIPHERY AND LATERAL SUPPORT REGIONS.

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FUEL ELEMENT (FE) TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
NUCLEAR CRITICALITY 3.1.1.1	REACTIVITY WORTH MEASUREMENTS OF FE		W1.1	W1.1
THERMAL AND FLUID CHARAC- TERISTICS 3.1.1.1.2	SINGLE ELEMENT CORROSION TESTS	T 1.001		
TEMPERATURE VARIATION 3.1.1.1.3	SINGLE ELEMENT CORROSION TEST	T 1.002		
	POWER DISTRIBUTION IN FE	W 3.1	W3.1	
	EFFECT OF PV, SHIELDS, NOZZLE ETC. OF FE POWER DISTRIBUTION		W3.2	
CORROSION AND REACTIVITY LOSS 3.1.1.1.5	SINGLE ELEMENT CORROSION TESTS	T 1.003 THRU 1.008	T 2.001 T 2.002	T 2.001 T 2.002
	CORRODED FE TIP STRENGTH	EB 1.02	EB 1.02	EB 1.02
	REACTIVITY WORTH MEASUREMENTS: IMPURITIES	W1.2	W1.2	
	CORRODED ELEMENTS	W1.3		
TIP CONFIGURATION 3.1.1.1.7	FE TIP LOAD AND THERMAL CYCLES	EB 2.02	EB 2.02	EB 2.02
	FE TIP AXIAL CREEP TEST	EB 3.02	EB 3.02	EB 3.02
	FE TIP FLEXTURAL TEST	EB 1.03	EB 1.03	EB 1.03
	FE TIP INTEGRITY	T 6.001	T 6.001	

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FUEL ELEMENT (FE) (CONT.)
TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
ELEMENT LEAKAGE 3.1.1.1.8	FE POROSITY MEASUREMENT AT REACTOR PRESSURE AND TEMPERATURE	T 6.002	T 6.002	T 6.001
CORROSION AND REACTIVITY LOSS 3.1.1.2.1	SINGLE ELEMENT CORROSION TEST	T 1.009	T 2.003	T 2.003
OPERATING ENVIRONMENT 3.1.2.4.1	VACUUM EFFECT ON FE STRENGTH	EK 3.01	EK 3.01	EK 3.01
TRANSPORTABILITY 3.1.2.5	MEASURE RADIATION ENVIRONMENT	W 4	W 4	
	VIBRATION TESTS	EB 3.01	EB 3.01	EB 3.01
INSTRUMENTATION 3.3.1.3	SINGLE ELEMENT CORROSION TESTS	T 1.010		
	SINGLE ELEMENT CORROSION TESTS	T 1.011		
MATERIALS, PARTS, AND PROCESSES 3.3.3	AMBIENT AND HIGH TEMPERATURE FLEX TESTS WITH BUNDLING LOAD	EB 1.05	EB 1.05	EB 1.05
	AMBIENT AND HIGH TEMPERATURE TENSILE AND COMP. TEST	EB 1.01	EB 1.01	EB 1.01
	REACTIVITY WORTH OF FE MATLS IN PAX/R-1 ASSEMBLY	W 1.1		

FUEL ELEMENT (FE) (CONT.)
TEST SUMMARY

ECC REQUIREMENT

TEST DESCRIPTION

DEV.

PREQUAL.

QUAL.

MOISTURE AND FUNGUS
RESISTANCE 3.3.5

MOISTURE AND FUNGUS
SINGLE ELEMENT CORROSION TEST

EB 9.01
T 1.004

EB 9.01

CORROSION OF PARTS
3.3.6

ENVIRONMENTAL TEST AS
REQUIRED

EB 9.02

EB 9.02

EB 9.02

SINGLE ELEMENT CORROSION TEST

T 1.012

T 2.004

T 2.004

STORAGE 3.3.11

SINGLE ELEMENT CORROSION TEST

T 1.004

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FUEL ELEMENT
SUMMARY OF PRESENTATION

A REFERENCE AND 3 ALTERNATE FUEL ELEMENT DESIGNS HAVE BEEN INVESTIGATED AND A DESIGN DIRECTION RECOMMENDED.

10 CYCLE OPERATION AT 4500°R NOZZLE CHAMBER TEMPERATURE IMPOSES SEVERE FUEL ELEMENT REQUIREMENTS.

THE COATING-MATRIX, ORIFICE-MATRIX, AND TIP-MATRIX INTERACTION STRESSES REQUIRE CONTINUED ANALYTICAL AND EXPERIMENTAL INVESTIGATION.

EVERY EFFORT TO MINIMIZE THE MAXIMUM ELEMENT TEMPERATURE IS REQUIRED.

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KEY REQUIREMENTS OF ECC

<u>ITEM</u>	<u>REQUIREMENT</u>
1. GEOMETRY TRANSITION	TRANSFORM THE CORE BOUNDARY INTO A CYLINDRICAL SURFACE.
2. BUNDLING LOAD	TRANSMIT TO THE CORE THE TOTAL MECHANICAL AND PNEUMATIC BUNDLING LOAD AT REACTOR OPERATING CONDITIONS.
3. FLOW IMPEDANCE	ACT AS A BARRIER TO IMPEDE RADIAL INFLOW FROM THE LATERAL SUPPORT SYSTEM AND IN CONJUNCTION WITH THE PERIPHERAL FUEL ELEMENTS IMPEDE AXIAL FLOW TO PERMIT MEETING OPERATING REQUIREMENTS.
4. THERMAL IMPEDANCE	PROVIDE A THERMAL IMPEDANCE TO MEET FUEL ELEMENT TEMPERATURE REQUIREMENTS.
5. RELIABILITY	RELIABILITY GOAL OF NOT LESS THAN 0.99969, RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

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CORE PERIPHERY

DESIGN CONCEPTS

<u>DESIGNATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN - COLD FILLERS, PYROFOIL WRAPPER	COLD FILLER STRIPS AND A 0.155 INCH PYROFOIL WRAPPER AS SHOWN ON LAYOUT 939J287
ALTERNATE NO. 1 - COLD FILLERS, HARD PYRO, WRAPPER	COLD FILLER STRIPS WITH A 0.055 INCH HARD PYRO INBOARD OF A 0.100 INCH PYROFOIL WRAPPER AS SHOWN ON LAYOUT 939J534
ALTERNATE NO. 2 - COATING INSIDE WRAPPER	NbC OR ZrC COATING ON FUEL ELEMENTS ADJACENT TO THE PYROFOIL WRAPPER (OR HARD PYRO) - (APPLICABLE TO EITHER LAYOUT 939J287 OR 939J534)

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CORE PERIPHERY REFERENCE DESIGN

CORE TOTALS

TIE TUBES	349
FUELED ELEMENTS	1878
PARTIAL ELEMENTS	NONE
LARGEST STRIP AVG	.94
SMALLEST STRIP AVG	.20
REGULAR CLUSTERS	253
IRREGULAR CLUSTERS	48
TOTAL CLUSTERS	301

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CORE PERIPHERY PREFERENCE DESIGN

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CORE PERIPHERY
AXIAL SUPPORT

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CORE PERIPHERY ALTERNATE NO.1

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CORE PERIPHERY

OUTLINE OF ANALYSIS

- A. CONCEPTUAL STRESS ANALYSIS
 - 1. FILLER STRIP STRESSES AND GAPS
 - 2. WRAPPER STRAIN
 - 3. INSULATING TILE STRESSES AND GAPS
- B. PRELIMINARY THERMAL AND HYDRAULIC ANALYSIS
 - 1. WRAPPER TEMPERATURES
 - 2. WRAPPER CORROSION
 - 3. FILLER STRIP TEMPERATURES

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CORE PERIPHERY FILLER STRIP STRESSES

MAX TENSILE STRESSES

TYPE OF STRESS	AXIAL DISTRIBUTIONS				
		(THINNEST F. S.)		(THICKEST F. S.)	
CURVATURE STRESS (BENDING)		REFERENCE DESIGN 150 PSI	ALTERNATE NO. 1 190 PSI	REFERENCE DESIGN 740 PSI	ALTERNATE NO. 1 940 PSI
RADIAL ΔT GRAD. STRESS (BENDING)		70 PSI	60 PSI	2460 PSI	1970 PSI
FRICTION STRESS (AXIAL)		700 PSI	700 PSI	158 PSI	160 PSI
SUPPORT STRESS (BENDING)		1500 PSI (3070) *	1500 PSI (3070)	0 PSI (500)	0 PSI (500)
		$\sigma_{T \text{ MAX}} = 2280 \text{ PSI}$ (3780)	$\sigma_{T \text{ MAX}} = 2280 \text{ PSI}$ (3780)	$\sigma_{T \text{ MAX}} = 3200 \text{ PSI}$ (3200)	$\sigma_{T \text{ MAX}} = 2900 \text{ PSI}$ (2900)
		AT STATION 2.4	AT STATION 2.4	AT STATION 32	AT STATION 32

MIN. ALLOWABLE BENDING = 3200 PSI

MIN. ALLOWABLE TENSILE = 2400 PSI

* NUMBERS IN PARENTHESIS ARE FOR THE CLEVIS TYPE HANGER SHOWN IN TME 1798.

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CORE PERIPHERY

CHANGE IN FILLER STRIP GAPS AT STEADY STATE

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CORE PERIPHERY WRAPPER STRAIN

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CORE PERIPHERY
INSULATING TILE STRESSES AT START UP
(ALTERNATE NO. 1)

CORE PERIPHERY

INSULATING TILE GAP (ALTERNATE NO. 1) AT STEADY STATE

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CORE PERIPHERY MAXIMUM OUTSIDE WRAPPER SURFACE TEMPERATURE VS FLOW RATE FOR AVERAGE THICKNESS FILLER STRIP

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CORE PERIPHERY
LOCAL GRAFOIL WRAPPER OUTER SURFACE
CORROSION FOR 75 MINUTES

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CORE PERIPHERY
PRELIMINARY FILLER STRIP TEMPERATURE
FOR AVERAGE THICKNESS FILLER STRIP

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CORE PERIPHERY

COMPARISON MATRIX OF DESIGN APPROACHES

REQUIREMENTS OR FEATURES	REFERENCE DESIGN COLD FILLERS, PYROFOIL WRAPPER	ALTERNATE NO. 1 COLD FILLERS, HARD PYRO, WRAPPER	ALTERNATE NO. 2 COATING INSIDE WRAPPER	
			REFERENCE	ALTERNATE 1
PERIPHERAL ELEMENT CHILLING	NONE	MEDIUM	VERY LOW	MEDIUM
PERIPHERAL ELEMENT CORROSION	VERY LOW	MEDIUM	NONE	NONE
WRAPPER I.D. CORROSION	VERY LOW	MEDIUM	LOW	HIGH
WRAPPER O.D. CORROSION	MEDIUM	LOW	MEDIUM	LOW
WRAPPER STRAIN CAPABILITY	HIGH*	MEDIUM*	HIGH*	MEDIUM*
INSULATING TILE STRESS	NONE	HIGH (SLIP PLANE REQ.)	NONE	VERY HIGH (SLIP PLANE REQ.)
COMPLEXITY OF ASSEMBLY	LOW	MEDIUM	LOW	MEDIUM
PERIPHERAL INTER- ELEMENT GAP SIZE	VERY SMALL	VERY SMALL	SMALL	SMALL
PERIPHERAL ELEMENT INTERFACE FRICTION	LOW	LOW	HIGH	HIGH
FILLER STRIP GAP SIZE	SMALL	MEDIUM	SMALL	MEDIUM

*FOR I.D.; MORE DATA REQUIRED FOR O.D.

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CORE PERIPHERY

RECOMMENDED DESIGN APPROACH

A CORE PERIPHERY CONSISTING OF COLD FILLER STRIPS AND WITH A PYROFOIL WRAPPER ADJACENT TO UNCOATED FUEL ELEMENTS (DRAWING NO. 939J287) IS RECOMMENDED FOR THE FOLLOWING REASONS:

1. DESIGN UTILIZES COLD FILLER STRIPS WHICH HAVE BEEN DEMONSTRATED IN NRX-A2 THROUGH NRX-A5 REACTORS TO BE CAPABLE OF OPERATION OVER A WIDE VARIETY OF STEADY-STATE AND TRANSIENT CONDITIONS WITHOUT BREAKAGE.
2. THE DESIGN UTILIZES A WRAPPER WHICH HAS BEEN SHOWN TO RESULT IN SIGNIFICANTLY REDUCED PERIPHERAL FUEL ELEMENT CORROSION IN THE NRX-A6 REACTOR AS CONTRASTED WITH PREVIOUS NRX REACTORS WHICH DID NOT EMPLOY A WRAPPER.
3. LOCATION OF THE WRAPPER DIRECTLY ADJACENT TO THE FUEL ELEMENT PROVIDES THE BEST POSSIBLE AXIAL AND RADIAL FLOW IMPEDANCE.
4. THE RECOMMENDED DESIGN ALLOWS THE UTILIZATION OF UNCOATED PERIPHERAL FUEL ELEMENTS WHICH RESULTS IN MINIMUM INTER-ELEMENT GAPS AND CORROSION OF THE SURFACE OF PERIPHERAL FUEL ELEMENTS AND THE INSIDE SURFACE OF THE WRAPPER.
5. PROVIDES INHERENT RELIABILITY BECAUSE OF SIMPLICITY IN DESIGN AND MANUFACTURE.
6. HAS BEST POTENTIAL OF MEETING ALL TECHNICAL AND FUNCTIONAL REQUIREMENTS.

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CORE PERIPHERY

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
BUNDLING LOADS 3.1.1.1.2	VERIFY CAPABILITY OF FILLERS AND WRAPPER TO WITHSTAND BUNDLING LOADS	EE 1.01	EE 1.01	EE 1.01
	VERIFY WRAPPER INTEGRITY UNDER DISTRIBUTED BUNDLING PRESSURES AND THERMAL EXPANSIONS	T 5.001	T 5.001	T 5.001
FLOW IMPEDANCE 3.1.1.1.3	VERIFY WRAPPER MATERIAL CORROSION RESISTANCE TO AXIAL FLOW	T 7.001	T 7.001	T 7.001
RADIAL FLOW 3.1.1.1.3.1	VERIFY WRAPPER RADIAL FLOW IMPEDANCE UNDER PRESSURE DIFFERENTIALS	EE 1.01	EE 1.01	EE 1.01
	VERIFY WRAPPER RADIAL FLOW IMPEDANCE THROUGHOUT CORROSIVE ENVIRONMENT DURATION	T 5.002	T 5.002	T 5.002
AXIAL FLOW 3.1.1.1.3.2	EVALUATE AXIAL IMPEDANCE OF WRAPPER JOINTS AND BENDS	EE 1.03		
	VERIFY AXIAL FLOW IMPEDANCE OF WRAPPER AGAINST FUEL PERIPHERY THROUGHOUT CORROSIVE ENVIRONMENT DURATION	T 5.003	T 5.003	T 5.003

CORE PERIPHERY

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
THERMAL IMPEDANCE 3.1.1.1.4	DETERMINE THERMAL IMPEDANCE OF PERIPHERY CONFIGURATIONS	T 7.002		
FILLER STRIP AXIAL LOADS 3.1.1.1.5	VERIFY CAPABILITY OF FILLER STRIP SUPPORTS TO CARRY AXIAL LOADS AND ACCOMMODATE CORE RADIAL GROWTH	EE 3.01	EE 3.01	EE 3.01
	DETERMINE FRICTION COEFFICIENTS OF PERIPHERY INTERFACES	EE 2.03		
WRAPPER EXPANSION 3.1.1.1.6	VERIFY WRAPPER MATERIAL STRAIN CAPABILITY OVER TEMPERATURE RANGE	EE 4.03	EE 4.03	EE 4.03
	INVESTIGATE WRAPPER FLEXING ACTION DURING CORE RADIAL EXPANSION	EE 1.02		
	DETERMINE EFFECTS OF HEAT UP RATES ON WRAPPER AND ASSEMBLY BONDING AGENTS	EE 4.04		
	INVESTIGATE ALTERNATE WRAPPER MATERIAL MECHANICAL PROPERTIES	EE 4.01		
	VERIFY WRAPPER AXIAL AND RADIAL EXPANSION CAPABILITY WITH DISTRIBUTED PRESSURE AND TEMPERATURE	T 5.004	T 5.004	T 5.004

CORE PERIPHERY

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
OPERATING ENVIRONMENT 3.1.2.4.1	DETERMINE RADIATION ENVIRONMENT AND HEATING RATES IN CORE PERIPHERY	W 4	W 4	
TRANSPORTABILITY 3.1.2.5	VERIFY CAPABILITY OF CORE PERIPHERY TO WITHSTAND TRANSPORTATION SHOCK AND VIBRATION LOADS	EG 1.01	EG 1.01	EG 1.01
GENERAL DESIGN FEATURES 3.3.1	MEASURE REACTIVITY WORTH OF CORE PERIPHERY HARDWARE	W 1	W 1	
	DETERMINE POWER DISTRIBUTION AND EFFECT OF CORE PERIPHERY COMPONENTS AND SHAPE THEREON	W 3	W 3	
INSTRUMENTATION 3.3.1.3	VERIFY STRUCTURAL CAPABILITY OF CORE PERIPHERY COMPONENTS MODIFIED FOR INSTRUMENTATION	EE 1.01	EE 1.01	EE 1.01
	VERIFY THERMAL AND FLOW PERFORMANCE OF INSTRUMENTED CORE PERIPHERY COMPONENTS	T 5.005	T 5.005	T 5.005

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CORE PERIPHERY

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
MOISTURE AND FUNGUS RESISTANCE 3.3.5	VERIFY MOISTURE AND FUNGUS RESISTANCE OF CLUSTER COMPONENTS	EE 9.01		EE 9.01
CORROSION OF PARTS 3.3.6	VERIFY CAPABILITY OF CORE PERIPHERY MATERIALS TO WITHSTAND VARIOUS EXPECTED ENVIRONMENTS WITHOUT ADVERSE CORROSION	EE 9.02	EE 9.02	EE 9.02
	VERIFY HYDROGEN CORROSION RESISTANCE OF CORE PERIPHERY COMPONENTS	T 5.006	T 5.006	T 5.006
	VERIFY HYDROGEN CORROSION NATURE AND RATES ON CORE PERIPHERY COMPONENTS	T 7.003	T 7.002	T 7.002
STORAGE 3.3.11	INVESTIGATE LONG TERM STORAGE ENVIRONMENT EFFECTS ON CORE PERIPHERY COMPONENTS	EE 9.03	EE 9.03	

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CORE PERIPHERY

SUMMARY OF PRESENTATION

1. TWO CORE PERIPHERY DESIGN APPROACHES PLUS AN ALTERNATE MODIFICATION TO EACH WERE PRESENTED. THE COLD FILLER WITH WRAPPER AND UNCOATED PERIPHERAL FUEL ELEMENTS IS RECOMMENDED FOR THE NERVA REACTOR DESIGN APPROACH.
2. THE RECOMMENDED DESIGN PLACES A COMBINED THERMAL AND FLOW BARRIER OF SIMPLE DESIGN DIRECTLY AGAINST THE FUEL PERIPHERY.
3. PRELIMINARY ANALYSES SHOWED GENERAL ACCEPTABILITY OF THE RECOMMENDED DESIGN TO MEET THE FUNCTIONAL REQUIREMENTS OF THE ECC. THE ANALYSES FURTHER SHOWED BETTER FLOW GAP CONTROL IN THE RECOMMENDED DESIGN.
4. A SUMMARY OF THE VERIFICATION TESTS WAS REVIEWED SHOWING DEVELOPMENT, PREQUALIFICATION, AND QUALIFICATION TESTS REQUIRED TO VERIFY THE ECC ADEQUACY. PARTICULAR EMPHASIS WILL BE PLACED ON EVALUATING WRAPPER FLEXING AND CORROSION CAPABILITY.

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LATERAL SUPPORT SYSTEM
KEY REQUIREMENTS OF LSS

<u>ITEM</u>	<u>REQUIREMENT</u>
● LATERAL RESTRAINT & CORE EXPANSION	PROVIDE A MECHANICAL SYSTEM FOR CENTERING THE CORE WHILE PERMITTING THE CORE TO CHANGE IN SIZE DUE TO TEMPERATURE CHANGES
● CORE MECHANICAL BUNDLING	PROVIDE MECHANICAL BUNDLING TO MEET THE REACTOR NONOPERATIONAL REQUIREMENTS
● CORE PNEUMATIC BUNDLING	PROVIDE, IN CONJUNCTION WITH OTHER COMPONENTS, THE REQUIRED MECHANICAL AND PNEUMATIC BUNDLING PRESSURE
● EMERGENCY SUPPORT	PROVIDE LATERAL SUPPORT REQUIRED TO MEET REQUIREMENTS IN THE EVENT OF LOSS OF COOLANT ACCIDENT
● RELIABILITY	RELIABILITY GOAL OF NOT LESS THAN 0.99996 RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

LATERAL SUPPORT SYSTEM

ALTERNATE DESIGN CONCEPTS

DESIGNATION

DESCRIPTION

REFERENCE DESIGN

ANGLE SEAL SEGMENTS AS SHOWN ON
LAYOUT 914E204

ALTERNATE NO. 1

FLAT SEAL SEGMENTS AS SHOWN ON
LAYOUT 914E203

ANGLE SEAL-SEGMENTED DESIGN

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FLAT SEAL-SEGMENTED DESIGN

FLAT SEAL-SOLID RING DESIGN

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LATERAL SUPPORT SYSTEM

STRUCTURAL ANALYSIS - MECHANICAL STRESS

	<u>ANGLE SEAL</u>	<u>FLAT SEAL</u>
● PLUNGER		
CALCULATED	2090 PSI	1280 PSI
ALLOWABLE	4800 PSI	4800 PSI
● SPRING		
RATE	30 LB/IN	80 LB/IN
PRELOAD	16.8 LB	28 LB
MAXIMUM POWER LOAD	31.2 LB	52 LB
STRESS	65,000 PSI	65,000 PSI
BUNDLING PRESSURE	3.0 PSI	3.34 PSI

LATERAL SUPPORT SYSTEM

STRUCTURAL ANALYSIS - DYNAMIC ANALYSIS

	<u>ANGLE SEALS</u>	<u>FLAT SEALS</u>
COEFFICIENT OF FRICTION	0.20	0.20
BREAKAWAY G LEVEL FOR NO SPRING MOTION	3.90	1.97
UNDAMPED NATURAL FREQUENCY	8.7 HZ	8.2 HZ
MAXIMUM DISPLACEMENT	.288 INCH	.288 INCH
OCCURS AT REFLECTOR ACCELERATION	4.40 G	2.22 G
AT A FREQUENCY OF	5.2 HZ	5.0 HZ
CORE IS ACCELERATED	4.94 G	2.50 G

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LATERAL SUPPORT SYSTEM

NUCLEAR ANALYSIS

REACTIVITY CHANGES DUE TO THE ALTERNATE LATERAL SUPPORT DESIGN*

<u>LATERAL SUPPORT DESIGN</u>	<u>WT. OF C</u>	<u>WT. OF METAL</u>	<u>REACTIVITY COEFFICIENT OF CARBON</u>	<u>REACTIVITY COEFFICIENT OF METAL</u>	<u>NET REACTIVITY CHANGE*</u>
	kgs	kgs	¢/kgs	¢/kgs	¢
<u>REFERENCE DESIGN</u>					
ANGLE SEAL SEGMENTS (DRAWING NO. 914E204)	127.2	< 1.0	+2.5	-4.0	0.0
<u>ALTERNATE DESIGN</u>					
FLAT SEAL SEGMENTS WITH METAL TIE BOLTS (DRAWING NO. 914E203)	115.5	20.0	+2.5	-4.0	-110.0

*RELATIVE TO REFERENCE DESIGN

LATERAL SUPPORT SYSTEM

COMPARISON MATRIX OF DESIGN APPROACHES

<u>REQUIREMENTS OR FEATURES</u>	<u>REFERENCE DESIGN ANGLE SEAL SEGMENTS 914E204</u>	<u>ALTERNATE NO. 1 FLAT SEAL SEGMENTS 914E203</u>
DYNAMIC LATERAL RESTRAINT	3.90 G	1.97 G
OUTER SEAL RETAINER LOADS	LOW	HIGH
SEAL MOTION	RADIAL AND AXIAL	RADIAL
PLUNGER STRESS	2090 PSI	1280 PSI
DRUM SPAN	7.00 \$	6.50 \$
PREVIOUS EXPERIENCE	NRX-A6	NRX-A1 THRU A5
TOLERANCES	HIGH	MEDIUM
ASSEMBLY SKILLS REQUIRED	HIGH	MEDIUM

LATERAL SUPPORT SYSTEM
RECOMMENDED DESIGN APPROACH

THE ANGLE SEAL DESIGN (DRAWING NO. 914E204) IS RECOMMENDED FOR THE FOLLOWING REASONS:

1. THE DESIGN APPROACH IS A LOGICAL EXTENSION OF THE TECHNOLOGY DEVELOPED AND PROVEN IN THE NRX-A6.
2. STATIONARY SEALS CAN BE RETAINED WITHOUT DEVELOPING NEW MATERIALS OR NEW LATCHING TECHNIQUES.
3. HAS THE BEST POTENTIAL OF MEETING ALL TECHNICAL AND FUNCTIONAL REQUIREMENTS.

LATERAL SUPPORT SYSTEM (LSS)
 TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
LATERAL RESTRAINT 3.1.1.1.1	STATIC DISPLACEMENT TESTS USING PARTIAL LENGTH CORE	EG 2.01	EG 2.01	EG 2.01
	DYNAMIC TESTS USING PARTIAL LENGTH CORE	EG 2.02	EG 2.02	EG 2.02
	DYNAMIC TESTS USING FULL LENGTH CORE		EG 1.01	EG 1.01
	REACTIVITY VS RADIAL CORE DISPLACEMENT	W 1.1	W 1.1	
	POWER DISTRIBUTION VS RADIAL CORE DISPLACEMENT	W 1.3		
CORE EXPANSION 3.1.1.1.2	STATIC DISPLACEMENT AND DYNAMIC TESTS USING LARGE CORE DIAMETER	EG 2.01	EG 2.02	EG 1.01
MECHANICAL BUNDLING 3.1.1.1.3	STATIC DISPLACEMENT AND DYNAMIC TESTS	EG 2.01	EG 1.01	EG 1.01
	REACTIVITY VS CORE BUNDLING	W 1.2	W 1.2	
	EFFECT OF BUNDLING FAILURE	W 1.4		
PNEUMATIC BUNDLING 3.1.1.1.4	MEASURE PRESSURE DROP THROUGH SIMULATED LSS GEOMETRY	T 6.001	T 6.001	T 6.001

LATERAL SUPPORT SYSTEM (LSS)
TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
INSULATION 3.1.1.1.5	EFFECT OF INSULATIONS IN SIMULATED LSS GEOMETRY	T 6.002		
FLOW CHARACTERISTICS 3.1.1.1.6	MEASURE LEAKAGE THROUGH SIMULATED LSS GEOMETRY	T 6.003	T 6.002	T 6.002
EMERGENCY SUPPORT 3.1.1.2.1	SPRING RELAXATION VS TEMPERATURE	ED 1.01	ED 3.05	ED 1.01
OPERATING ENVIRONMENT 3.1.2.4.1	MEASURE RADIATION IN AND AROUND THE LSS	W 4	W 4	
TRANSPORTABILITY 3.1.2.5	LOW FREQUENCY DYNAMIC TESTS	EG 5.03	EG 5.03	EG 1.02
GENERAL DESIGN FEATURES 3.3.1	SEAL RETENTION TEST	ED 3.03		
	DESIGN PROPERTIES OF MATERIALS	ED 3.04		
	FIND REACTIVITY WORTH OF LSS MATERIALS	W 1.3	W 1.3	
	EFFECT OF LSS MATERIALS ON POWER DISTRIBUTION	W 3	W 3	

LATERAL SUPPORT SYSTEM (LSS)
TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
INSTRUMENTATION 3.3.1.3	APPLICATION STUDIED DURING DYNAMIC TESTS	EG 4.00	EG 4.00	EG 4.00
	MOUNTED IN SIMULATED REACTOR CONFIGURATION AND ENVIRONMENT	T 6.004	T 6.003	T 6.003
MOISTURE AND FUNGUS RESISTANCE 3.3.5	SPECIAL ENVIRONMENTAL TESTS	EG 5.01		EG 5.01
CORROSION OF PARTS 3.3.6	COMPONENT PART MATERIAL CORROSION DATA GENERATED WHERE REQUIRED	EG 5.02	EG 5.02	EG 5.02
	COMPONENT PARTS EXPOSED TO SIMULATED REACTOR ENVIRONMENT	T 7.001	T 7.001	T 7.001
STORAGE 3.3.11	NORMAL REACTOR BUILDS OR PARTS STORAGE TESTS	EG 5.03	EG 5.03	

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LATERAL SUPPORT SYSTEM

SUMMARY OF PRESENTATION

1. ANGLED AND FLAT SEALS HAVE BEEN CONSIDERED AS DESIGN APPROACHES FOR THE LATERAL SUPPORT SYSTEM.
2. THE ANGLED SEAL DESIGN HAVING BOTH INNER AND OUTER SEALS SEGMENTED IS RECOMMENDED FOR THE NERVA REACTOR.
3. THE RECOMMENDED DESIGN USES MATERIALS AND LATCHING TECHNIQUES DEVELOPED IN PREVIOUS REACTORS.
4. ANALYSIS SHOWED THE RECOMMENDED DESIGN PROVIDES GREATER DYNAMIC CAPABILITY THAN THE ALTERNATE.
5. A SUMMARY OF THE TEST PROGRAM COVERING DEVELOPMENT, PREQUALIFICATION, AND QUALIFICATION TESTS SHOWS PARTICULAR EMPHASIS WILL BE PLACED ON EVALUATING DYNAMIC CHARACTERISTICS.

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REFLECTOR AND AXIAL SUPPORT SYSTEM

KEY REQUIREMENTS OF RASS

<u>ITEM</u>	<u>REQUIREMENT</u>
• NEUTRON REFLECTION	PROVIDE FOR ACCOMMODATING CONTROL DRUMS WITH THE NUCLEAR CONTROL WORTH MINIMUM OF $\$7.0 \pm \0.5 .
• AXIAL AND RADIAL SUPPORT	CAPABILITY OF TRANSMITTING ALL LOADS FROM NSS COMPONENTS WITHIN THE PRESSURE VESSEL TO THE NOZZLE FLANGE AND PROVIDE RADIAL LOADS REQUIRED FOR LATERAL SUPPORT OF THE CORE.
• RADIAL LEAKAGE	PROVIDE A FLOW BARRIER TO PREVENT RADIAL LEAKAGE OF THE COOLANT INTO THE LATERAL SUPPORT SYSTEM.
• EMERGENCY SUPPORT	CAPABILITY OF TRANSMITTING 1 - G AXIAL LOAD FOR ONE HOUR FOLLOWING A LOSS-OF-COOLANT ACCIDENT.
• RELIABILITY	RELIABILITY GOAL OF NOT LESS THAN 0.99985 RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

REFLECTOR AND AXIAL SUPPORT SYSTEM

ALTERNATE DESIGN CONCEPTS

<u>DESIGNATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN - RINGS WITH RADIAL SLOTS	RINGS WITH RADIAL SLOTS TO INNER TIE BOLTS (AFT SUPPORTED CORE) AS SHOWN ON DRAWING 939J535.
ALTERNATE NO. 1 - SECTORIZED RINGS	SECTORIZED CIRCUMFERENTIALLY, IN THREE AXIAL LENGTHS, AS SHOWN ON DRAWING 939J349.
ALTERNATE NO. 2 - CANNED RINGS	RINGS WITH DRUM BORES AND REFLECTOR O.D. CANNED AS SHOWN ON DRAWING 939J315.
ALTERNATE NO. 3 - SECTORIZED REFLECTOR WITH INNER BARRELS	SECTORIZED FULL LENGTH REFLECTOR WITH INNER GRAPHITE BARREL (SIMILAR TO NRX-A5) AS SHOWN ON DRAWINGS 981D540 AND 939J540.

REFLECTOR, RINGS WITH RADIAL SLOTS

939J535

APPROX. CONTROL DRUM WORTH: \$7.00

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AXIAL SUPPORT SYSTEM

612524-24B

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AXIAL SUPPORT SYSTEM

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CONTROL DRUM

612524-24B

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REFLECTOR, SECTORIZED RINGS

939J349

612524-18B

REFLECTOR, SECTORIZED RINGS

939J349

612524-17B

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REFLECTOR, CANNED RINGS 939J315

APPROX. CONTROL DRUM WORTH: \$6.85

612524-19B

SECTORIZED REFLECTOR WITH INNER GRAPHITE BARREL

NRX-A5

981D540

APPROX. CONTROL DRUM WORTH: \$7.00

612524-208

SECTORIZED REFLECTOR WITH INNER GRAPHITE BARREL (SPLIT AT DRUMS)

939J540

APPROX. CONTROL DRUM WORTH: \$5.60

612884-210

REFLECTOR AND AXIAL SUPPORT SYSTEM

OUTLINE OF ANALYSIS

NUCLEAR ANALYSIS

CONTROL DRUM SPAN REQUIREMENT
CONTROL DRUM SPAN FOR DESIGN ALTERNATES

RADIATION ANALYSIS

THERMAL AND FLUID FLOW ANALYSIS

NRX-A6 POST TEST ANALYSIS SUMMARY
NERVA DESIGN ANALYSIS SUMMARY

NOMINAL NERVA DRUM SPAN UTILIZATION

C/H COLD TO HOT REACTIVITY CHANGE
TOTAL DRUM SPAN REQUIREMENT = \$7.0

NERVA CONTROL DRUM SPAN COEFFICIENTS

<u>DESIGN PERTURBATIONS</u>	<u>PERCENTAGE CHANGE IN NERVA REFERENCE DRUM SPAN</u>
EFFECT OF CHANGING FROM LOW VOID TO HIGH VOID FUEL (0.099 IN. TO 0.110 IN.)	0%
REDUCTION IN NUMBER OF DRUMS FROM 18 TO 12	-20%
INCREASING VANE OUTER DIAMETER BY 1.0 IN.(SAME BERYLLIUM WEB THICKNESS AS BASE)	+54%.
DOUBLING VANE THICKNESS	+8%
ADDITION OF A BORATED STEEL SIDE SHIELD (1.25 INCHES THICK)	+10%
INCREASING VANE ARC FROM 120° TO 180°	-20%

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EFFECT OF CONTROL VANE B¹⁰ SURFACE DENSITY
ON CONTROL DRUM SPAN

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EFFECT OF REFLECTOR DESIGN ON CONTROL DRUM SPAN

<u>DESIGN</u>	<u>DRUM SPAN</u>	<u>CONTROL VANE DIAMETER INCREASE (IN.) FOR \$7. SPAN</u>	<u>PRINCIPAL CAUSE FOR SPAN CHANGE</u>
REFERENCE RINGS, 3. 14 INCH VANE OUTER DIAMETER	\$7. 0	---	---
ALTERNATE 1 SECTORIZED RINGS	\$5. 8	0. 40	TITANIUM SPACERS
ALTERNATE 2 RINGS, CANNED			
ALUMINUM OR ZIRCONIUM CANS	\$6. 8	0. 05	ALUMINUM OR ZIRCONIUM CANS
TITANIUM OR STAINLESS STEEL CANS	\$5. 9	0. 30	TITANIUM OR STAINLESS STEEL CANS
ALTERNATE 3 SECTORS, GRAPHITE INNER REFLECTOR			
4. 41 INCH REFLECTOR THICKNESS WITH WEBS, 3. 56 INCH VANE O. D.	\$7. 0	NONE	THIS DESIGN INCORPORATES INCREASED VANE DIAMETER
3. 67 INCH REFLECTOR THICKNESS, NO WEBS	\$5. 6	0. 47	CORE TO VANE DISTANCE INCREASED WITH LEAF SPRINGS IN BETWEEN

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MAJOR OBJECTIVES OF NRX-A6 POST TEST

REFLECTOR ANALYSIS

DETERMINE THE ADEQUACY OF THE ANALYTICAL TECHNIQUES
USED IN THE DESIGN EFFORT

FIND THE OPERATING CONDITIONS CAUSING THE CRACKING
AND DETERMINE THE FAILURE STRESS

ESTABLISH PERMISSIBLE BERYLLIUM OPERATING CONDITIONS
FOR APPLICATION TO FUTURE DESIGN

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THERMAL MODEL INPUT CHANGES FROM
PRE-TEST ANALYSIS MODEL

<u>INPUT PARAMETER</u>	<u>CHANGE</u>
MEASURED REFLECTOR INLET TEMPERATURE	-13°R SOL/ -9°R EOL
MEASURED REFLECTOR TOTAL HEAT PICKUP	-16% SOL/ -10% EOL
FLOW INLET AND EXIT LOSS COEFFICIENTS	NEGLIGIBLE
REFLECTOR-VESSEL ANNULUS EFFECTIVE FLOW IMPEDANCE FROM MEASURED DATA	+100% ANNULUS FLOW - 9% REFLECTOR FLOW
IMPROVED HEAT TRANSFER CORRELATION	+15°R
WANL BERYLLIUM THERMAL CONDUCTIVITY	+15% SOL/ -35% EOL
INCREASED COOLANT CHANNEL INDEPENDENCE	NEGLIGIBLE

NRX-A6 REFLECTOR

COMPARISON OF PREDICTION AND POST TEST CALCULATED TEMPERATURES WITH MEASURED DATA AT START OF FULL POWER HOLD

* LOCATED AT STATION 17
ALL OTHERS ARE AT STATION 21

LOCATION	A ⁽¹⁾ CRT 14400	B ⁽²⁾ PREDICTED	C ⁽³⁾ POST CALCULATIONS	A-B	A - C
1	362	352	364	+10	- 2
1	348	352	364	- 4	-16
2	378	338	344	+40	+34
2	348	338	344	+10	+ 4
3	348	362	352	-14	- 4
3	375	362	352	+13	+23
4	331	355	350	-24	-19
4	350	355	350	- 5	0
5	298	319	322	-21	-24
5	315	319	322	- 4	- 7
6*	221	251	220	-30	+ 1
6	221	251	220	-30	+ 1

(1) MEASURED VALUE CORRECTED EXCEPT FOR INSTALLATION ERROR

(2) WANL-TME- 1642 (15 MINUTE INTO FULL POWER HOLD)

(3) CALCULATED WITH PHASE II MODEL AND INPUT DATA

NRX-A6 REFLECTOR

COMPARISON OF PREDICTION AND POST TEST CALCULATED TEMPERATURES WITH MEASURED DATA AT END OF FULL POWER HOLD

*LOCATED AT STATION 17
ALL OTHERS ARE AT STATION 21

LOCATION	A ⁽¹⁾ CRT 17800	B ⁽²⁾ PREDICTED	C ⁽³⁾ POST CALCULATIONS	A-B	A-C
1	378	352	405	+26	-27
1	365	352	405	+13	-40
2	421	338	388	+83	+33
2	390	338	388	+52	+ 2
3	400	362	405	+38	- 5
3	429	362	405	+67	+24
4	376	355	409	+21	-33
4	389	355	409	+34	-20
5	332	319	390	+13	-58
5	346	319	390	+27	-44
6*	220	251	230	-31	-10
6	222	251	230	-29	- 8

- (1) MEASURED VALUE CORRECTED EXCEPT FOR INSTALLATION ERROR
(2) WANL-TME-1642 (15 MINUTE INTO FULL POWER HOLD)
(3) CALCULATED WITH PHASE II MODEL AND INPUT DATA

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CONCLUSION FROM NRX-A6
POST TEST REFLECTOR ANALYSIS

MEASURED AND CALCULATED TEMPERATURES COMPARED WELL AT START OF LIFE. NO CRACKING WAS INDICATED AT THIS CONDITION.

THERMAL CONDUCTIVITY OF THE BERYLLIUM DECREASED NOTICEABLY WITH RUN TIME AND RESULTED IN INCREASED TEMPERATURE DIFFERENCES.

THE OUTER WEBS CRACKED APPROXIMATELY TWO MINUTES BEFORE SHUTDOWN INITIATION. THIS RESULTED IN EITHER CRACKING OR OPENING EXISTING CRACKS AT THE INNER WEBS.

THE CRACKING DID NOT AFFECT THE PERFORMANCE OF THE NUCLEAR SUBSYSTEM.

THE RESULTS OF THE ANALYSIS, WHEN COMPLETED WILL PROVIDE USEFUL DATA FOR NERVA DESIGN

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REFLECTOR SYSTEM SUMMARY

	<u>CASE R1-5</u>	<u>CASE R1-3</u>	<u>CASE R1-8</u>	<u>NRX-A6</u> <u>MEASURED SOL</u>
<u>REFLECTOR O.D. DESIGN</u>	<u>NO SLEEVE</u>	<u>BORAL SLEEVE</u>	<u>BORAL SLEEVE</u>	<u>NO SLEEVE</u>
<u>MIDPLANE HEAT FLUX IN</u> <u>FROM LATERAL SUPPORT</u> <u>(BTU/HR - IN²)</u>	2275	2275	1525	2275
<u>MIDPLANE MATERIAL</u> <u>TEMPERATURES (°R)</u>				
MAXIMUM	524	518	488	>386
(MAX-AVG)	(135)	(95)	(69)	(> 80)
AVERAGE	389	423	419	306
(AVG-MIN)	(80)	(89)	(67)	(85)
MINIMUM	309	334	352	221
<u>REFLECTOR SYSTEM ΔP (PSID)</u>				
CONTROL VANE SLOT	40-50	40-50	40-50	16.2
REFLECTOR	21.9	22.1	24.2	16.2
REFLECTOR/PV	1.0	1.2	1.2	2.2
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REFLECTOR MIDPLANE TEMPERATURE DISTRIBUTION
FOR CASE R1-8

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EFFECT OF REFLECTOR DESIGN ON THERMAL ANALYSIS

<u>DESIGN</u>	<u>REFLECTOR TEMPERATURE DIFFERENTIALS</u>	<u>LSS INTERFACE</u>	<u>RADIAL LEAKAGE</u>
REFERENCE RINGS	$\sim 70^{\circ}\text{R}$	CONTINUOUS SURFACE	NEGLECTIBLE
ALTERNATE 1 SECTORIZED RINGS	$\sim 70^{\circ}\text{R}$	DISCONTINUOUS SURFACE	REQUIRES AXIAL SEALS
ALTERNATE 2 RINGS, CANNED	$\sim 70^{\circ}\text{R}$ INCREASED UNCERTAINTY	CONTINUOUS SURFACE	NEGLECTIBLE
ALTERNATE 3 SECTORS, GRAPHITE INNER REFLECTOR	REDUCED ΔT THIN WEBS CAN BE ELIMINATED	CONTINUOUS SURFACE	PLUNGER PIN LEAKAGE

REFLECTOR AND AXIAL SUPPORT SYSTEM

OUTLINE OF STRUCTURAL ANALYSIS

- REVIEW OF NRX-A6 RESULTS
- NERVA REFLECTOR CONCEPTUAL ANALYSIS SUMMARY
- STRUCTURAL EVALUATION OF OTHER AXIAL SUPPORT COMPONENTS

RESULTS OF NRX-A6 REFLECTOR PROGRAM

THERMAL AND STRESS ANALYSES HAVE GIVEN THE FOLLOWING RESULTS:

- THE REFLECTOR OUTER CONTROL DRUM WEBS FAILED VERY NEAR THE END OF THE FULL POWER HOLD. THERMAL/STRESS ANALYSES CONFIRM THIS FAILURE, SINCE STRESSES WERE ABOVE THE MATERIAL ULTIMATE TENSILE STRENGTH AS OBTAINED IN GTR IRRADIATION TEST PROGRAMS.
- INNER WEBS DID NOT FAIL DUE TO HIGH THERMAL GRADIENTS AROUND COOLING HOLES, BUT MOST PROBABLY FAILED DUE TO STRESS REDISTRIBUTION WHEN OUTER WEBS CRACKED. WORK CONTINUING.
- OUTER WEB STRESSES INCREASED CONTINUALLY THROUGH THE RUN, DUE TO THE LOWERING OF THERMAL CONDUCTIVITY WITH IRRADIATION FLUENCE.
- CALCULATED STRESSES OF GREATER THAN 30,000 PSI WERE WITHSTOOD FOR PRACTICALLY THE FULL RUN DURATION.
- THE INCREASED KNOWLEDGE OF:
 1. CHANGE IN THERMAL CONDUCTIVITY WITH IRRADIATION FLUENCE
 2. VARIATIONS IN FLOW DISTRIBUTION
 3. VARIATIONS IN INTERNAL HEATING
 4. IMPROVEMENTS IN ANALYTICAL MODELING TECHNIQUESWILL IMPROVE CONFIDENCE IN NERVA REFLECTOR THERMAL/STRESS ANALYSIS.

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NRX-A6 OUTER WEB STRESSES VERSUS FAST FLUENCE

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NRX-A6 INNER WEB MODELS

DETAILED INNER WEB MODEL

REFLECTOR MODEL

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NRX-A6 INNER WEB END-OF-LIFE TEMPERATURES AND STRESSES (STA. 26)

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TEMPERATURE DISTRIBUTION

IN-PLANE STRESS DISTRIBUTION

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NRX-A6 STRESS REDISTRIBUTION RESULTS

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NERVA REFLECTOR PARAMETRIC STUDIES

- EFFECT OF I.D. HEAT FLUX
- EFFECT OF BORAL SLEEVE ON O.D.
- EFFECT OF INCREASED INTERNAL HEATING RATE
- EFFECT OF FLOW REDISTRIBUTION
- STUDIED ABOVE EFFECTS FOR:
 - RINGS
 - SECTORS
 - SLOTTED TO VARIOUS DEPTHS AT TIE BOLT LOCATIONS

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EFFECT OF SLOT DEPTH ON REFLECTOR STRESSES

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EFFECT OF BORAL SLEEVE ON MAX. IN PLANE STRESS

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EFFECT OF I.D. HEAT FLUX ON MAX. IN-PLANE STRESS

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EFFECT OF INCREASED INTERNAL HEATING ON IN-PLANE STRESSES

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STRESS EVALUATION OF REFERENCE AND ALTERNATE REFLECTOR DESIGNS

	<u>MAX TENSILE STRESS</u>	<u>LOCATION</u>
REFERENCE - SLOTTED TO INNER TIE BOLT	7,100 PSI IN-PLANE 13,500 PSI AXIAL	C.D. BORE INNER WEB
ALTERNATE 1 - SECTORIZED RINGS	7,700 PSI IN-PLANE 12,100 PSI AXIAL	C.D. BORE INNER WEB
ALTERNATE 2 - CANNED RINGS	SIMILAR TO REFERENCE DESIGN	
ALTERNATE 3 - SECTORIZED REFLECTOR WITH INNER BARREL	REFLECTOR STRESSES LIKE NRX-A5 ≈ 12,700 PSI AXIAL BARREL STRESSES SLIGHTLY LOWER THAN NRX-A (3850 PSI)	

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COMPARISON OF BERYLLIUM STRENGTH WITH REACTOR OPERATING STRESS AT FULL POWER

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REFLECTOR AND AXIAL SUPPORT SYSTEM
COMPARISON MATRIX OF DESIGN APPROACHES

REQUIREMENTS OR FEATURES	REF. DESIGN, RINGS WITH RADIAL SLOTS (939J535)	ALT. NO. 1 - SECTORIZED RINGS (939J349)	ALT. NO. 2 - CANNED RING (939J315)	ALT. NO. 3 - SECT. REFL. W/ INNER BARREL (981D540)	VARIATION OF ALT. NO. 3 (939J540)
DRUM SPAN	\$7.00	\$5.80	\$6.85	\$7.00(+2.830")	\$5.60(+1.570")
LSS INTERFACE	ACCEPTABLE	UNACCEPT.	ACCEPTABLE	NOT APPL(I.R.)	NOT APPL(I.R.)
LSS SPRING CAPABILITY	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	MARGINAL	MARGINAL
TOLERANCES REQ.	MEDIUM	HIGH	HIGH	LOW	LOW
RADIAL LEAKAGE	ACCEPTABLE	DOUBTFUL (AXIAL SEAL)	ACCEPTABLE	DOUBTFUL (PLUNGER PIN)	DOUBTFUL (PLUNGER PIN)
WEIGHT	LOWEST	MEDIUM	LOW	HIGHEST	HIGH
ASSM. & FIXT. TECH.	DEVELOPED	REQ. DEVEL.	REQ. DEVEL.	NEW FIXTURE	REQ. DEVEL & NEW FIXT.
PREVIOUS EXPER.	NRX-A6	NONE	NONE ON CANS	NRX-A5	NONE
ANAL. DEPTH AND DETAIL REQUIRED	HIGH	HIGH	HIGH	LOW	LOW
STEADY-STATE STRESS	LOW (SLOT STRESSES)	LOW (RING INTERACTIONS)	LOW (THERMAL UN- CERTAINTIES)	LOW (LOW THERMAL GRADIENT)	LOW (LOW THERMAL GRADIENT)
INNER REFLECTOR	NONE	NONE	NONE	REQUIRED	REQUIRED

REFLECTOR AND AXIAL SUPPORT SYSTEM

RECOMMENDED DESIGN APPROACH

IT IS RECOMMENDED THAT THE REFLECTOR AXIAL SUPPORT SYSTEM DESIGN PROCEED ALONG THE LINES OF THE RING WITH RADIAL SLOTS (DRAWING NO. 939J535) AND WITH CONTINUED STUDIES OF ALTERNATE DESIGN FEATURES TO THE BASIC DESIGN, TO IMPROVE THE REFLECTOR IN ITS PERFORMANCE MARGIN. THE REASONS FOR THIS RECOMMENDATION ARE AS FOLLOWS:

1. HAS THE POTENTIAL OF BEING DEVELOPED TO MEET ALL TECHNICAL AND FUNCTIONAL REQUIREMENTS WITHIN THE PRESCRIBED ENVELOPE AND WITH THE MOST EFFICIENT UTILIZATION OF MATERIALS.
2. EXPERIENCE WITH THE ANALYSIS OF NRX-A6 RESULTS HAS PROVIDED GUIDANCE IN SELECTING DESIGN FEATURES WHICH HAVE THE POTENTIAL TO SATISFY THE STRUCTURAL REQUIREMENTS.
3. THIS DESIGN PROVIDES A FLOW BARRIER WHICH PREVENTS RADIAL LEAKAGE OF THE COOLANT INTO THE LATERAL SUPPORT SYSTEM WITH MINIMUM SEALING. THE DESIGN PERMITS SIMPLE MANUFACTURING AND ASSEMBLY TECHNIQUES.
4. DESIGN HAS FEATURES WHICH WILL LEAD TO THE DEVELOPMENT OF AN INHERENTLY RELIABLE DESIGN.

THE SUPPORT PLATE RECOMMENDATION IS MADE IN CONJUNCTION WITH THE SUPPORT STEM FEED AND DISCHARGE SYSTEM.

REFLECTOR AND AXIAL SUPPORT SYSTEM (RASS)

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
NEUTRON REFLECTION 3.1.1.1.1	REACTIVITY WORTH OF BERYLLIUM, AND POSSIBLE IMPURITIES IN THE REFLECTOR	W 1.1	W 1.1	
	MEASURE CONTROL WORTH OF RASS	W 2.1	W 2.1	W 2.1
	EFFECT OF PRESSURE VESSEL AND SIDE SHIELDS ON RASS REACTIVITY CONTROL CHARACTERISTICS		W 1.5	
	EFFECT OF NOZZLE AND OTHER COMPO- NENTS ON RASS REACTIVITY CONTROL CHARACTERISTICS		W 1.6	
	EFFECT OF TEST CELL C ENVIRONMENT ON NERVA REACTIVITY		W 2.2	
AXIAL SUPPORT 3.1.1.1.2	REACTIVITY WORTH OF AXIAL SUPPORT HARDWARE	W 1.2	W 1.2	
	BERYLLIUM PROPERTIES TEST (WOL, DCB STRAIN, CYCLING, AND BI-AXIAL TEST FIXTURES)	EA 2.01	EA 2.01	
	AXIAL SUPPORT LOAD AND VIBRATION TESTS	EA 6.01	EA 6.01	EA 6.01
	LOAD DEFLECTION TEST, FORWARD END SEAL (REACTOR SEAL TEST FIXTURE)		EF 4.01	
	LOAD DEFLECTION TEST, NOZZLE END SEAL TEST (REACTOR NOZZLE END SEAL TEST FIXTURE)		EF 5.01	

REFLECTOR AND AXIAL SUPPORT SYSTEM (RASS)

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
RADIAL SUPPORT 3.1.1.1.3	REACTIVITY WORTH OF RADIAL SUPPORT HARDWARE	W 1.3	W 1.3	
	RADIAL SUPPORT LOAD AND VIBRATION TESTS	EA 6.02	EA 6.02	EA 6.02
RADIAL LEAKAGE 3.1.1.1.4	REFLECTOR RADIAL SEAL LEAKAGE TESTS (RADIAL SEAL TEST FIXTURE)	EA 3.01	EA 3.03	
	RASS-RADIAL LEAKAGE SEAL TESTS (RADIAL SEAL TEST FIXTURE)	T 6.001	T 6.001	T 6.001
FLOW CHARACTERISTICS 3.1.1.1.5	REFLECTOR AND AXIAL SUPPORT SYSTEM FLOW CHARACTERISTICS USING SIMULATED GEOMETRY	T 6.002		
	REACTIVITY WORTH OF HYDROGEN IN THE REFLECTOR	W 1.4	W 1.4	
CONTROL DRUM ROTATION 3.1.1.1.6	CONTROL PLATE THERMAL TEST (THERMAL GRADIENT FACILITY)	EA 5.01	EA 5.01	
	CONTROL DRUM ROTATION AND POSI- TIONING TESTS (3 DRUM FIXTURE AND 18 DRUM FIXTURE)	EA 5.02	EA 5.02	EA 5.02

REFLECTOR AND AXIAL SUPPORT SYSTEM (RASS)

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
DRUM TORQUE 3.1.1.1.7	DRUM TORQUE TESTS (3 DRUM FIXTURE AND 18 DRUM FIXTURE)	EA 5.02	EA 5.02	EA 5.02
CORE SUPPORT PLATE DEFLECTION 3.1.1.1.9	MEASURE DEFLECTION OF CORE SUPPORT PLATE (CORE SUPPORT PLATE LOAD FIXTURE)	EA 6.01	EA 6.01	EA 6.01
OPERATING ENVIRONMENT 3.1.2.4.1	FLUX, DOSE, AND RADIATION HEATING DISTRIBUTION IN RASS WITH AND WITHOUT HYDROGEN	W 4.1	W 4.1	
	FLUX, DOSE AND EFFECTS OF NOZZLE AND PRESSURE VESSEL ON RASS RADIATION ENVIRONMENT	W 4.2	W 4.2	
	EFFECTS OF FACILITY SHIELDS ON RASS RADIATION ENVIRONMENT		W 4.3	
TRANSPORTATION 3.1.2.5	EFFECTS OF TRANSPORTATION ENVIRONMENTS	EA 6.06	EA 6.06	EA 6.06
INSTRUMENTATION 3.3.1.3	INSTRUMENTATION EFFECTS TESTS	EA 6.03	EA 6.03	EA 6.03
	INSTRUMENTATION EFFECTS USING SIMULATED REACTOR	T 6.003	T 6.002	T 6.002

REFLECTOR AND AXIAL SUPPORT SYSTEM
SUMMARY OF PRESENTATION

1. FOUR REFLECTOR AND AXIAL SUPPORT DESIGNS WERE PRESENTED. A RING DESIGN WITH RADIAL SLOTS TO THE INNER TIE BOLTS IS RECOMMENDED FOR THE NERVA REACTOR.
2. THE NRX-A6 ANALYSIS PROGRAM HAS GIVEN US A BETTER UNDERSTANDING OF THE FACTORS RESPONSIBLE FOR CRACKING OF THE REFLECTOR, IMPROVING OUR ABILITY TO DESIGN THE NERVA REFLECTOR.
3. SEVERAL SIGNIFICANT DESIGN IMPROVEMENTS HAVE BEEN MADE IN THE RECOMMENDED NERVA REFLECTOR ALL OF WHICH LOWER THE STRESSES FROM THOSE EXPERIENCED IN THE NRX-A6.
 - SLOTS BETWEEN DRUMS
 - BORAL SLEEVE ON O.D.
 - I.D. INSULATION
 - RADIAL KEYS
4. THE RECOMMENDED DESIGN IS THE ONLY CONCEPT STUDIED THAT REQUIRES NO ENVELOPE CHANGE TO MEET THE DRUM SPAN REQUIREMENTS.
5. THE REFLECTOR TEST PROGRAM WAS REVIEWED SHOWING HOW DEVELOPMENT, PREQUALIFICATION AND QUALIFICATION REQUIREMENTS WOULD BE MET.

GANGED DRUM DRIVE SYSTEM

- REQUIREMENTS OF ECC
- DESCRIPTION OF DESIGN CONCEPTS
- DISCUSSION OF ANALYSIS RESULTS
- COMPARISON MATRIX OF DESIGN CONCEPTS
 - * RECOMMENDED APPROACH
- TEST VERIFICATION REQUIREMENTS

GANGED DRUM DRIVE SYSTEM

KEY REQUIREMENTS OF GDDS

<u>ITEM</u>	<u>REQUIREMENT</u>
DRUM POSITIONING	PROVIDE THE CAPABILITY OF TRANSMITTING TORQUE FROM SIX ACTUATORS FOR SYNCHRONOUS POSITIONING OF 18 CONTROL DRUMS IN WHICH THE MAXIMUM SPREAD IN POSITION OF ALL DRUMS IS WITHIN 2 DEGREES OF ANY OTHER CONTROL DRUM.
TORQUE TRANSMISSION AND DECOUPLING	PROVIDE THE CAPABILITY OF RECEIVING UP TO 350 IN-LB. OF TORQUE FROM THE ACTUATOR AND TRANSMITTING UP TO 40 IN-LB. OF TORQUE TO EACH OF 18 CONTROL DRUMS.
MALFUNCTIONS	PROVISION FOR FUNCTIONING WITH ONE FAILED ACTUATOR AND TWO STUCK DRUMS.
RELIABILITY	RELIABILITY GOAL OF NOT LESS THAN 0.99996 RELATIVE TO THE STRUCTURAL, THERMAL, AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

GANGED DRUM DRIVE SYSTEM

ALTERNATE DESIGN CONCEPTS

<u>DESIGNATION</u>	<u>DESCRIPTION</u>
REFERENCE DESIGN - TITANIUM BANDS, GANGED FORWARD OF REFLECTOR	GANGED DRUM DRIVE SYSTEM MOUNTED ON THE FORWARD CONTROL DRUM SHAFT ADJACENT TO THE REFLECTOR AND INTERCONNECTED WITH TITANIUM BANDS (939J532).
ALTERNATE NO. 1 - TITANIUM BANDS, GANGED FORWARD OF EXTENSION SHIELD	GANGED DRUM DRIVE SYSTEM SUPPORTED INDEPEN- DENT OF THE REFLECTOR AND LOCATED FORWARD OF OF THE EXTENSION SHIELD (981D548).
ALTERNATE NO. 2 - MECHANICAL LINKAGE	CONTROL DRUMS INTERCONNECTED WITH MECHANICAL LINKS RATHER THAN BANDS (939J308).
ALTERNATE NO. 3 - AXIAL SPLINE TOOTH ACTUATOR DECOUPLER	SAME AS REFERENCE DESIGN EXCEPT THAT THE ACTUATOR SHEAR PIN IS REPLACED WITH A DECOUPLER HAVING SPRING LOADED TEETH (939J868).

GANGED DRIVE SYSTEM

GANGED DRUM DRIVE SYSTEM BAND END ATTACHMENTS

GANGED DRUM DRIVE SYSTEM

SECTION VIEW OF MECHANISM

SCHEMATIC OF ACTUATOR DECOUPLER

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GANGED DRUM DRIVE SYSTEM AXIAL SPLINE TOOTH ACTUATOR DECOUPLER

GANGED DRUM DRIVE SYSTEM

GANGED DRUM DRIVE SYSTEM LINKAGE MECHANISM

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GANGED DRUM DRIVE SYSTEM

ANALYSIS OF DESIGN CONCEPT

- STATIC LOAD ANALYSIS
- STATIC STRESS AND MARGIN OF SAFETY
- DYNAMIC ANALYSIS

GANGED DRUM DRIVE SYSTEM

STATIC LOAD ANALYSIS

I. NORMAL DRUM OPERATION

A. ASSUMPTIONS

1. NO FRICTION IN THE SYSTEM
2. BAND PRELOAD = 150 LBS.
3. ACTUATORS SHARE LOAD EQUALLY

B. RESULTS

1. BAND LOAD = 150 LBS.

II. MALFUNCTION CASE

A. ASSUMPTIONS

1. TWO LOCKED DRUMS AND A STUCK ACTUATOR OCCUR SIMULTANEOUSLY
2. RESISTING TORQUE OF DECOUPLER WITH LOCKED DRUMS = 80 IN-LB
(70 + 10 IN-LB)/DRUM
3. RESISTING TORQUE OF SHEAR PIN DUE TO A STUCK ACTUATOR = 575 IN-LB
(525 + 50 IN-LB)
4. RESISTING TORQUE OF REMAINING DRUMS DUE TO POSSIBLE BEARING FRICTION = 40 IN-LB/DRUM
5. BAND PRELOAD = 150 LBS.
6. ACTUATORS SHARE LOAD EQUALLY

B. RESULTS

1. MAXIMUM BAND LOAD = 290 LBS.

GANGED DRUM DRIVE SYSTEM
 STATIC STRESS AND MARGIN IN TITANIUM BAND

	PRIMARY STRESS		SECONDARY BENDING	COMBINED
	DIRECT ($\frac{P}{A}$)	+ THERMAL ($E\alpha\Delta T$)	STRESS ($\frac{Et}{D+t}$)	STRESS
<u>I. STEADY STATE OPERATION</u>				
A. NORMAL OPERATION	20,000 PSI	+	58,500 PSI	78,500 PSI
ALLOWABLE STRESS	89,000 PSI	0		195,000 PSI
	(.87x.85x120,000)			(1.5x130,000)
MARGIN OF SAFETY	340%			150%
B. MALFUNCTION CASE ▼	38,700 PSI	+	58,500 PSI	97,200 PSI
ALLOWABLE STRESS	89,000 PSI	0		195,000 PSI
MARGIN OF SAFETY	130%			100%
<u>II. STARTUP</u>				
A. NORMAL OPERATION	20,000 PSI	+ 24,000 PSI *	58,500 PSI	102,900 PSI
ALLOWABLE STRESS	102,000 PSI			225,000 PSI
	(.87x.85x138,000)			(1.5x150,000)
MARGIN OF SAFETY	130%			120%
B. MALFUNCTION CASE ▲	38,700 PSI	+ 24,400 PSI *	58,500 PSI	121,600 PSI
ALLOWABLE STRESS	102,000 PSI			225,000 PSI
MARGIN OF SAFETY	60%			85%

▼ P_B STEADY = 290 POUNDS

▲ P_B START = 470 POUNDS

* MAXIMUM TEMPERATURE DIFFERENCE
 BETWEEN MID PLANE REFLECTOR AND
 REFLECTOR EXIT GAS DURING PULSE
 COOLING

GANGED DRUM DRIVE SYSTEM

DYNAMIC ANALYSIS

I. ANALYTICAL MECHANICAL MODELS SET UP

- A. THE THREE-DRUM NR-1 MODEL WILL BE USED TO:
 - 1. CHECK OUT ANALYTICAL TECHNIQUES
 - 2. COMPARE ANALYTICAL RESULTS WITH THE EML THREE-DRUM TEST
- B. THE EIGHTEEN-DRUM R-1 MODEL WILL BE USED TO:
 - 1. OBTAIN STRUCTURAL INFORMATION ON TRANSIENT MOTIONS AND LOADS IN COMPONENTS FOR R-1 COMPONENT STRESS ANALYSIS

II. OBJECTIVES INCLUDED IN THE PROPOSED ANALYSIS

- A. DETERMINE:
 - 1. NATURAL FREQUENCIES AND MODE SHAPES OF SYSTEM
 - 2. SYSTEM RESPONSE AFTER A FAILURE OF A SHEAR PIN
 - 3. DRUM OVERSHOOTS AFTER ONE OR MORE STUCK DRUMS RELEASE
 - 4. STATIC POSITION OF EACH DRUM IF ONE OR MORE DRUMS RUN WITH A HIGH TORQUE
 - 5. DRUM RESPONSE FOR VARIOUS RAMPS AND ACCELERATIONS
 - 6. BAND LOADS WHEN ACTUATOR INPUT TORQUES ARE NOT EQUAL
 - 7. LIMIT CYCLES, IF ANY, THAT ARE PRESENT DUE TO EITHER ACTUATOR NONLINEARITY OR LARGE AMPLITUDE DECOUPLER MOTIONS
 - 8. WHETHER ANY HIGH FREQUENCY OSCILLATIONS ARE PRESENT WHICH COULD CAUSE BAND FATIGUE

GANGED DRUM DRIVE SYSTEM

COMPARISON MATRIX OF MECHANISM DESIGN APPROACHES

<u>REQUIREMENTS OR FEATURES</u>	<u>REFERENCE DESIGN BAND MECHANISM ADJACENT TO REFLECTOR</u>	<u>ALTERNATE NO. 1 BAND MECHANISM ABOVE EXTENSION</u>	<u>ALTERNATE NO. 2 LINKAGE MECHANISM</u>
SYSTEM INERTIA	LOW	MEDIUM	HIGH
REDUNDANT SYSTEM	YES	YES	NO
RIGIDITY OF SUPPORT OF MECHANISM	GOOD	POOR	GOOD
TOLERANCES REQUIRED	HIGH	HIGHEST	LOW
WEIGHT	LOW	HIGH	MEDIUM
RADIATION WINDOW	LARGE	LEAST	LARGE
BEARING OR JOINTS REQUIRED PER CONTROL DRUM	4	6	9
BRGS OPERATING - NORMAL	2	4	7
BRGS OPERATING - STUCK DRUM	2	2	7
SYSTEM FRICTION	LOWEST	LOW	HIGHEST
TORQUE AVAILABLE TO DRUMS	CONSTANT	CONSTANT	POSITION DEPENDENT
ACCEPTANCE OF THERMAL GRADIENTS	BAND ACTS AS SPRING	BAND ACTS AS SPRING	RIGID LINKAGE LOADS JOINTS

GANG DRUM DRIVE SYSTEM

COMPARISON MATRIX OF ACTUATOR DECOUPLER APPROACHES

<u>REQUIREMENTS OR FEATURES</u>	<u>REFERENCE DESIGN - SHEAR PIN</u>	<u>ALTERNATE NO. 3 - AXIAL SPLINE TOOTH</u>
FUNCTIONAL CHECK OF DECOUPLING TORQUE	SAMPLING OF LOT	ACTUAL DEVICE
DECOUPLING TORQUE	MATERIAL, SIZE, AND TEMPERATURE DEPENDENT	FRICTION, LOAD, AND TEMPERATURE DEPENDENT
INERTIA	LOW	HIGH
WEIGHT	LOW	HIGH
DESIGN AND FABRICATION	SIMPLE	MORE COMPLEX
ACTION AFTER DECOUPLED	LOW TORQUE - PERMANENTLY DISENGAGED	HIGH TORQUE - CONTINUOUSLY RE-ENGAGES AND DISENGAGES AS SYSTEM PASSES SEIZED ACTUATOR POSITION
SPACE ENVELOPE	SMALL	LARGE

GANGED DRUM DRIVE SYSTEM

RECOMMENDED DESIGN APPROACH

IT IS RECOMMENDED THAT THE GANGED DRUM DRIVE SYSTEM BE SUPPORTED INDEPENDENTLY OF THE REFLECTOR AND LOCATED FORWARD OF THE EXTENSION SHIELD (AS SHOWN IN DRAWING NO. 98 ID548) FOR THE FOLLOWING REASONS:

1. MOUNTING ABOVE THE EXTENSION SHIELD MINIMIZES THE RADIATION WINDOW.
2. DESIGN PERMITS EASY ADJUSTMENT OF EXTENSION SHIELD THICKNESS.
3. HAS THE BEST POTENTIAL OF MEETING ALL THE TECHNICAL AND FUNCTIONAL REQUIREMENTS OF THE REACTOR.

GANGED DRUM DRIVE SYSTEM

TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
DRUM POSITIONING 3.1.1.1.1	CAPABILITY OF THE GDDS TO HOLD CONTROL DRUM POSITIONS WITHIN 2° OF ANY OTHER DRUM (18 DRUM RIG)	EA 4.03	EA 4.03	EA 4.03
	POWER AND TEMPERATURE DISTRIBUTION CAUSED ON THE CORE BY RELATIVE POSITION ACCURACY OF THE DRUMS	W 3	W 3	
BACKLASH 3.1.1.1.2	DETERMINE THE ACTUAL BACKLASH THAT EXISTS IN THE GDDS	EA 4.02	EA 4.03	EA 4.03
TORQUE TRANS- MISSION AND DECOUPLING 3.1.1.1.3	CAPABILITY TO TRANSMIT TORQUE TO EACH CONTROL DRUM AND DECOUPLE STUCK CONTROL DRUMS AND AN ACTUATOR	EA 4.02	EA 4.03	EA 4.03
	DRIVE BAND TESTS - TO PROVIDE DATA ON TENSILE, COMBINED TENSILE & BENDING, FATIGUE, AND END ATTACHMENT DESIGN	EA 4.01	EA 4.01	
	DETERMINE THE DECOUPLING CAPABILITY AND CHARACTERISTICS AFTER DECOUPLING OF THE ACTUATOR DECOUPLER	EA 4.04	EA 4.04	

GANGED DRUM DRIVE SYSTEM

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
DRUM RATE 3.1.1.1.4	DETERMINE THE VELOCITY, ACCELERATION AND DECELERATION CAPABILITIES OF THE GDDS (18 DRUM RIG)	EA 4.02	EA 4.03	EA 4.03
MALFUNCTIONS 3.1.1.2.1	DETERMINE THE EFFECTS ON THE GDDS OF AN INOPERATIVE STUCK ACTUATOR IN CONJUNCTION WITH TWO STUCK CONTROL DRUMS (18 DRUM RIG)	EA 4.03	EA 4.03	EA 4.03
OPERATING ENVIRONMENT 3.1.2.4.1	MEASURE RADIATION ENVIRONMENT OF COMPONENTS TO DETERMINE HEATING RATES & FOR RADIATION EFFECTS EVALUATION	W 4	W 4	
TRANSPORTABILITY 3.1.2.5	DETERMINE EFFECTS OF VIBRATION AND SHOCK ON COMPONENTS	EA 4.02	EA 4.02	EG 1.01
SAFETY 3.1.2.7	DETERMINE EFFECT ON DRUM ROTATION OF THE FAILURE OF ANY ONE COMPONENT OF THE GDDS (18 DRUM RIG)	EA 4.03	EA 4.03	EA 4.03
MOISTURE & FUNGUS RESISTANCE 3.3.5	DETERMINE RESISTANCE OF MATERIALS UTILIZED AND COMPONENTS TO FUNGUS	EA 9.02	EA 9.02	EA 9.02

GANGED DRUM DRIVE SYSTEM

TEST SUMMARY (CONTINUED)

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
CORROSION OF PARTS 3.3.6	STUDY EFFECTS OF EXPECTED NSS CORROSION ENVIRONMENTS ON COMPONENTS	EA 9.02	EA 9.02	EA 9.02
STORAGE 3.3.1.1	DEMONSTRATE THAT COMPONENTS WILL NOT BE ADVERSELY AFFECTED BY STORAGE PRIOR TO NSS USAGE	EA 9.03	EA 9.03	

GANGED DRUM DRIVE SYSTEM

SUMMARY OF PRESENTATION

1. GANGING OF THE CONTROL DRUMS BY TWO DIFFERENT METHODS WAS PRESENTED. TWO DEVICES FOR DECOUPLING A JAMMED ACTUATOR WERE ALSO PRESENTED. THE RECOMMENDED DESIGN APPROACH IS THE BAND DRIVE SYSTEM WITH A SHEAR PIN ACTUATOR DECOUPLER.
2. TO MOST EFFECTIVELY PLACE THE SHIELDING, IT IS RECOMMENDED THAT THE GDDS BE LOCATED FORWARD OF THE EXTENSION SHIELD.
3. PRELIMINARY ANALYSIS OF THE DRIVE BAND INDICATES A SATISFACTORY MARGIN OF SAFETY EVEN FOR THE MOST PESSIMISTIC MALFUNCTION CONDITION.
4. ADDITIONAL DEVELOPMENT AND ANALYSIS IS REQUIRED TO DETERMINE SYSTEM AND COMPONENT RESPONSE AND INTEGRITY FOR VARIOUS DYNAMIC LOADS AND DEMANDS OF THE SYSTEM.

GANGED DRUM DRIVE SYSTEM — BAND FATIGUE TEST

BANDS TO BE CYCLED 10^6 TIMES
(APPROXIMATELY 60 HOURS)

40 BANDS TO BE TESTED

TESTING TO BE PERFORMED AT ROOM AND
CRYOGENIC TEMPERATURES

612524-13B

GANG DRIVE SYSTEM-BAND SPOT WELD TEST

- THREE SPECIMENS TESTED TO FAILURE AT ROOM TEMPERATURE TO DATE
 - $P_1 = 1050 \text{ LBS}$
 - $P_2 = 1200 \text{ LBS}$
 - $P_3 = 985 \text{ LBS}$
- 9 ADDITIONAL SPECIMENS TO BE TESTED TO FAILURE AT ROOM TEMPERATURE
- 9 ADDITIONAL SPECIMENS TO BE TESTED TO FAILURE AT CRYOGENIC TEMPERATURE

612524-12B

GANGED DRUM DRIVE SYSTEM ACTUATOR SHEAR PIN TEST

TESTS COMPLETED TO DATE

NO.	SHEAR TORQUE	TORQUE REQUIRED (IN. LBS) AFTER SHEAR (10 CYCLES)		DIAMETRAL CLEARANCE	CONDITION
		MAX.	AVG.		
1	850 IN. LBS.	18.6	9.8	.002-.004	NEOLUBE
2	800 IN. LBS.	7.4	2.1	.002-.004	MOLY
3	900 IN. LBS.	18.6	11.3	.002-.004	NO LUB
4	850 IN. LBS.	14.9	4.5	.004-.006	NEOLUBE
5	900 IN. LBS.	9.9	2.4	.004-.006	MOLY
6	900 IN. LBS.	19.8	5.9	.004-.006	NO LUBE

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GANGED DRUM DRIVE SYSTEM

SECTION VIEW OF MECHANISM

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MECHANICAL PORTION SHIELD PRESENTATION

July 17, 18, 19, 1968

INTRODUCTION

(U) This portion of the shield presentation illustrates typical mechanical designs for the types of shields being considered. A slightly modified version of alternate 3 as described by Mr. Friedman is used as a base, since with the modification the design includes appropriate examples. The purpose is twofold 1) to illustrate the general proposed construction and 2) to illustrate the proposed method of increasing or decreasing the amount of shield material in the various shields and the affect on other NSS parts.

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SHIELD, TOP AND SIDE

939J518

STATION
0

BY PASS SUPPLY

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TYPICAL SHIELD MODULE

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VIEWGRAPH 1

(CRD) This viewgraph will serve to illustrate the overall design, and at least schematically illustrate some of the other structures occupying the space. For the purpose of orientation the top of the core is shown in outline, the shield below the support plate, the core support plate, the support stem feed and effluent plena, a piping space, auxiliary support plate, shield above the support plate, extension shield associated with the shield above the support plate, extension shield associated with the shield below the support plate and a side shield. A brief description of features of the shield below the support plate, shield above the support plate and side shield will be given.

VIEWGRAPH 2

(CRD) The shield below the support plate is of a modular construction. Each module consists of 7 hexagonal bars of Bath, located and retained between end plates. The hexagonal bars have an across flats dimension that matches the average size of a fuel cluster. The bars have central bores which accommodate the core support system hardware at assembly. A cylinder of shield material assembled with the support stem partially fills the space when the core parts are assembled to the core support plate. The whole module is located to the core support plate by a series of standoffs and dowels and retained by a single hollow bolt with locking device.

(CRD) The construction permits changes in the amount of shield material by lengthening or shortening the hexagonal bars. Because of the location of the shield changes in shield length modify the SSA, core support structure, PV and perhaps other structures. The construction also permits changes in the cooling hole pattern.

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SHIELD CROSS SECTION

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VIEWGRAPH 3

(U) This viewgraph completes the picture of this shield showing the assembly of this shield beginning with regular modules at the center and continuing toward the periphery. Irregular modules fill in the periphery to make a cylindrical shape.

The extension shield associated with this central shield is shown on this viewgraph also. The shield consists of almost square bars of Bath set in rows to the required radial dimension. The bars are the length of the required longitudinal dimension of the shield. A typical flow pattern is shown which can be modified to suit the thermal analysis requirements. The amount of shield material can be changed by lengthening or shortening bars or changing the number of rows of bars. No change in NSS parts is required if the shield change is within the space provided.

VIEWGRAPH 4

(U) The shield above the support plate with its associated extension shield are shown on this viewgraph. The central shield consists of two equal assemblies separated by a plenum. The purpose being to offset the flow holes in each part eliminating straight through holes.

The shield is built on an auxiliary support structure. As shown the shield material is built up in layers. It was intended that this shield be made from two materials, for example, the thicker layer might be borated Titanium Hydride in blocks or bars and the thinner layer might be Borated Copper or Borated Stainless Steel in plates.

The extension shield associated with the shield above the support plate is also of layered construction. The extension shield is supported from a complete ring support plate mounted on the auxiliary support plate flange.

The layered construction permits addition or subtraction of shield material, changes in proportion of the two materials, or other changes with a minimum of change in other NSS parts. Because of the shield location changes in physical size affect only piping, PV size, drive shafts and the like.

If a single material were chosen for the shield the construction would be in modules similar to that described for the shield below the support plate. The two part central shield would be maintained however.

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(U) In summary, the mechanical design of the shield has been guided by two basic principles.

- 1) Providing adequate mechanical structure for the shield.
- 2) Providing the maximum versatility so that the shield requirements can be met with a minimum of changes to NSS parts.

At this point I will turn the presentation back to Mr. Friedman for the final recommendations.

SHIELD

1. INTRODUCTION
2. REQUIREMENTS
3. ALTERNATE SHIELD ARRANGEMENTS
4. THERMAL AND NUCLEAR EFFECTS OF ALTERNATES
5. MECHANICAL DESIGN DETAILS
6. RECOMMENDED SHIELD ARRANGEMENT
7. TEST REQUIREMENTS
8. SUMMARY

SHIELDS
FUNCTIONAL AND TECHNICAL REQUIREMENTS

1. COMPONENT PROTECTION (3.1.1.1.1)

PROVIDE AN EXTERNAL RADIATION ENVIRONMENT TO MEET THE NSS COMPONENT LIMITATION AND THE ENGINE COMPONENT LIMITATION.

2. PROPELLANT TANK PROTECTION (3.1.1.1.2)

PROVIDE AN EXTERNAL RADIATION ENVIRONMENT TO MEET THE PROPELLANT TANK HEATING LIMITATIONS.

3. CREW PROTECTION (3.1.1.1.3)

ALLOW INSTALLATION OF ADDITIONAL INTERNAL SHIELDS TO PROVIDE THE EXTERNAL RADIATION ENVIRONMENT CONSISTENT WITH THE REQUIREMENTS.

4. RADIATION STREAMING (3.1.1.1.5)

MINIMIZE THE NUMBER AND SIZE OF AXIAL HOLES TO REDUCE RADIATION STREAMING.

5. RELIABILITY (3.1.2.1)

RELIABILITY GOAL OF NOT LESS THAN 0.99996 RELATIVE TO THE STRUCTURAL, THERMAL AND NUCLEAR FAILURES WHICH WOULD RESULT IN MISSION FAILURE.

SHIELD DESIGNS CONSIDERED

IDENTIFICATION

DESCRIPTION

REFERENCE DESIGN
SHIELD AFT OF PLATE

12-INCH CENTRAL SHIELD BELOW SUPPORT PLATE.
7.5-INCH EXTENSION SHIELD ABOVE GANGED DRUM DRIVE
SYSTEM (DRAWING 939J340).

ALTERNATE NO. 1
SHIELD AFT OF PLATE, LINER

14-INCH CENTRAL SHIELD BELOW SUPPORT PLATE,
18-INCH EXTENSION SHIELD BELOW GANGED DRUM DRIVE
SYSTEM, 0.125-INCH BORAL LINER (DRAWING 939J531).

ALTERNATE NO. 2
SHIELD FORWARD OF PLATE,
LINER

12-INCH CENTRAL SHIELD ABOVE SUPPORT PLATE,
21-INCH EXTENSION SHIELD BELOW THE GANGED DRUM DRIVE
SYSTEM, 0.125-INCH BORAL LINER (DRAWING 939J520).

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**12 IN. CENTRAL SHIELD WITH 7.5 IN. EXTENSION
LOCATED BELOW SUPPORT PLATE**

939J340

612528 - 8B

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R-1 SHIELD DESIGN CONFIGURATION II

Central Shield: 14" BATH (82 gm/cm²) Below Support Plate

Extension Shield: 18" BATH (104 gm/cm²) Below Ganged Drive
with 1/8" Boral Liner

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R-1 SHIELD DESIGN CONFIGURATION IV

Central Shield: 12" BATH (69.7 gm/cm^2) Above Support Plate

Extension Shield: 21" BATH (122 gm/cm^2) Below Ganged Drive
with 1/8" Boral Liner

SUPPORT STEM
FEED AND DISCHARGE
SYSTEM

OVERFLOW &
EFFLUENT PLENUM

CFTT FEED
PLENUM

SHIELD 12"

SUPPORT PLATE

CORE

GANGED
DRIVE
SYSTEM

EXTENSION
SHIELD

CLUSTER ASSY.
AND MISC.
HARDWARE

1/8" BORAL
PLATE

REFLECTOR
AND AXIAL
SUPPORT
SYSTEM

CLUSTER HOT
END SUPPORT
HARDWARE

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DESIGN CONSIDERATIONS FOR CENTRAL SHIELD
LOCATED BELOW THE SUPPORT PLATE

PROS

1. NO PENETRATIONS IN SHIELD FOR SUPPORT STEM FEED AND OVERFLOW PIPING.
2. LOW THERMAL GRADIENTS AND BOW IN CORE SUPPORT PLATE.
3. LOW BENDING STRESS IN SUPPORT STEM.
4. COOLANT CHANNEL LOCATION UNRESTRICTED BY CORE SUPPORT STRUCTURE.

CONS

1. CLOSE TOLERANCES REQUIRED FOR SUPPORT STEM PENETRATIONS.
2. LOCATION OF COOLANT CHANNELS RESTRICTED BY SUPPORT STEM.
3. HIGHER VOID FRACTION THAN THERMALLY NECESSARY BECAUSE OF SUPPORT STEM PENETRATIONS.
4. RADIATION STREAMING DUE TO SUPPORT STEM PENETRATION IN SHIELD.

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DESIGN CONSIDERATIONS FOR EXTENSION SHIELD
BELOW THE GANGED DRUM DRIVE

PROS

1. ELIMINATES RADIATION LEAKAGE OUT THE GANGED DRUM DRIVE LOCATION.

CONS

1. REQUIRES ADDITIONAL BEARINGS FOR DRUM DRIVE.
2. INCREASES ALIGNMENT DIFFICULTIES.

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EFFECT OF HEAT DEPOSITION ON MAIN PROPELLANT

		<u>WITH REFERENCE SHIELD DESIGN</u>	<u>WITH SHIELD ALTERNATE DESIGN 3</u>
PUMP DISCHARGE	P(PSIA)	921	936
	T(°R)	53.3	53.3
	W(LB/SEC)	88.8	88.8
REFLECTOR INLET	P(PSIA)	703	719
	T(°R)	193	193
	W(LB/SEC)	67.5	67.5
CORE INLET	P(PSIA)	619	619
	T(°R)	283	343
	W(LB/SEC)	88.8	88.8
CHAMBER CONDITION	P(PSIA)	450	450
	T(°R)	4500	4500
	W(LB/SEC)	88.8	88.8

SUMMARY OF THE SHIELD REACTIVITY EFFECTS

<u>SHIELD DESIGN</u>	<u>CENTRAL SHIELD WORTH</u>	<u>SIDE SHIELD WORTH</u>	<u>NET REACTIVITY INCREASE DUE TO PRESENCE OF SHIELDS</u>
REFERENCE DESIGN	\$0.62	---	\$0.62
ALTERNATE NO. 3	\$0.62	\$0.58*	\$1.20
BORAL LINER (1/8-INCH)	---	\$0.02	---

*ALSO INCREASES CONTROL DRUM SPAN BY \$0.29 AND REDUCES REQUIRED FUEL LOADING BY 2%.

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RECOMMENDED DESIGN APPROACH

1. CENTRAL SHIELD LOCATED ABOVE THE SUPPORT PLATE.
2. GANGED DRUM DRIVE MECHANISM LOCATED ABOVE THE EXTENSION SHIELD.
3. PROVISION FOR ATTACHING BORAL LINERS AROUND THE DOME AND AROUND THE PERIPHERY OF REFLECTOR.
4. PROVISION FOR ADJUSTING THICKNESS OF CENTRAL AND PERIPHERAL SHIELD AND FOR THE ADDITION OF SIDE SHIELDING IF REQUIRED FOR MANNED APPLICATION.

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BASIS FOR RECOMMENDED DESIGN APPROACH

1. LOCATION OF THE CENTRAL SHIELD ABOVE THE SUPPORT PLATE ELIMINATES THE RADIATION STREAMING ASSOCIATED WITH A SHIELD BELOW THE SUPPORT PLATE WHICH IS PENETRATED BY THE SUPPORT STEMS.
2. LOCATION OF THE GANGED DRUM DRIVE MECHANISM ABOVE THE EXTENSION SHIELD REDUCES RADIATION LEAKAGE.
3. PROVISION IS MADE FOR SIDE SHIELDS IF REQUIREMENTS DICTATE.
4. THE RECOMMENDED SHIELD LOCATIONS PERMIT THE REACTOR DESIGN TO PROCEED WITH MINIMUM INTERACTIONS WITH SHIELD REQUIREMENTS.
5. THE DESIGN CONCEPTS WILL LEND THEMSELVES TO IMPLEMENTATION INTO DESIGNS WITH INHERENT RELIABILITY. THE CONCEPTS ARE FLEXIBLE ENOUGH TO BE ADAPTED TO CHANGES IN SHIELD REQUIREMENTS.

SHIELD
TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PRE-QUAL.</u>	<u>QUAL.</u>
COMPONENT PROTECTION 3.1.1.1.1	MEASUREMENT OF INTERNAL AND EXTERNAL RADIATION ENVIRONMENT	W4.1	W4.1	W4.1
PROPELLANT TANK PROTECTION 3.1.1.1.2	MEASUREMENT OF INTERNAL AND EXTERNAL RADIATION ENVIRONMENT	W4.2	W4.2	W4.2
CREW PROTECTION 3.1.1.1.3	MEASUREMENT OF EXTERNAL RADIATION ENVIRONMENT	W4.5	W4.5	W4.3
FLOW CHARACTERISTICS 3.1.1.1.4	SHIELD MODULES TESTED TO DETERMINE FLOW AND PRESSURE DROP IN CHANNELS AND LEAKAGE PATHS (TFL)	T6.001	T6.001	----
STREAMING 3.1.1.1.5	MEASUREMENT OF INTERNAL AND EXTERNAL RADIATION ENVIRONMENT	W4.4	W4.4	W4.4
OPERATING ENVIRONMENT 3.1.2.4.1	COMPREHENSIVE MEASUREMENT OF RADIATION ENVIRONMENT	W4	W4	
GENERAL DESIGN FEATURES 3.3.1	REACTIVITY WORTH MEASUREMENTS	W1 W3	W1 W3	
	FLOW CHARACTERISTICS WITH INSTRUMENTATION TFL	T6.002	T6.002	T6.002
	LOAD AND DEFLECTION CAPABILITY EFL	EM2.01		EM2.01

SUMMARY

1. FINAL SHIELDING REQUIREMENTS ARE NOT YET DEFINED.
2. SEVERAL FEASIBLE SHIELD ARRANGEMENTS HAVE BEEN ANALYZED.
3. THE RECOMMENDED DESIGN HAS A CENTRAL SHIELD ABOVE THE SUPPORT PLATE AND AN EXTENSION SHIELD BELOW THE GANGED DRUM DRIVE.
4. THE RECOMMENDED DESIGN WILL HAVE MINIMAL EFFECT ON NSS DESIGN NO MATTER WHAT THE FINAL REQUIREMENTS.
5. THE PROPOSED SHIELD DESIGN CAN BE BUILT.
6. THE EFFECT OF THE SHIELD ON REACTOR NEUTRONICS ARE ACCEPTABLE.
7. AN EXTENSIVE TEST PROGRAM IS REQUIRED.

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- REQUIREMENTS OF ECC SPECIFICATION

<u>ITEM</u>	<u>REQUIREMENTS</u>
POISON WIRE AND CLUSTER INTERACTION (3.1.1.1.3)	<p>INSERTION OF THE POISON WIRES INTO THE CORE SHALL NOT DAMAGE THE COOLANT CHANNELS OR THE CLUSTER HARDWARE.</p> <p>THE POISON WIRES SHALL NOT DEGRADE THE CORROSION RESISTANCE OF THE FUEL ELEMENTS OR CLUSTER HOT END SUPPORT HARDWARE DURING THE PERIOD OF TIME THAT THE WIRES REMAIN INSTALLED.</p> <p>THE ACPWS SHALL BE CAPABLE OF BEING WITHDRAWN THROUGH THE NOZZLE AT A RATE NOT TO EXCEED 0.15 FPS, WITHOUT DAMAGE TO REACTOR OR NOZZLE.</p>
HIGH TEMPERATURE CAPABILITY (3.1.1.1.4)	<p>THE POISON MATERIAL SHALL WITHSTAND A TEMPERATURE OF 1475°F FOR A PERIOD OF 30 MINUTES AND STILL LIMIT THE MULTIPLICATION FACTOR TO A VALUE NOT GREATER THAN 0.95.</p>

ANTI-CRITICALITY POISON WIRES SYSTEM (ACPWS)

- REQUIREMENTS OF ECC SPECIFICATION

<u>ITEM</u>	<u>REQUIREMENTS</u>
POSITIVE SHUTDOWN (3.1.1 AND 3.1.1.1.1)	THE ACPWS SHALL PROVIDE POSITIVE REACTOR SHUTDOWN SUCH THAT THE EFFECTIVE MULTIPLICATION FACTOR (K_{eff}) IS LESS THAN 0.95 DURING HANDLING, SHIPPING, STORAGE, BOOST AND FLIGHT PHASE PRIOR TO NUCLEAR STAGE OPERATION. THIS INCLUDES THE EVENTUALITY OF FLOODING THE REACTOR WITH WATER, LIQUID HYDROGEN, OR OTHER HYDROGENOUS FLUID.
POISON WIRE RETENTION (3.1.1.1.2)	THE POISON WIRES SHALL BE RETAINED WITHIN (TBD) INCH OF THEIR INSTALLED POSITION IN THE FUEL ELEMENT CHANNELS UNDER THE ABOVE CONDITIONS AND DURING COLD FLOW ACCEPTANCE TESTING.

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- REQUIREMENTS OF ECC SPECIFICATION

316	<u>ITEM</u>	<u>REQUIREMENTS</u>
	RADIATION RESISTANCE (3.1.1.1.5)	THE POISON WIRES SHALL BE CAPABLE OF WITH- STANDING THE ENVIRONMENT RESULTING FROM SPACE RADIATION.
	CORROSION RESISTANCE (3.1.1.2.3)	THE POISON WIRES SHALL NOT LOSE THEIR POISONING CAPABILITY WHEN SUBJECTED TO SEA WATER FOR ONE YEAR.

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- DESIGN DESCRIPTION

DESIGNATION

DESCRIPTION

BACKGROUND

EVALUATION OF ALTERNATE DESIGNS FOR THE ACPWS WAS PERFORMED IN PREVIOUS CONTRACT YEARS. THESE EVALUATIONS LED TO THE SELECTION OF A FLEXIBLE POISON WIRE CONTAINING $B_4^{10}C$. THEREFORE, ONLY THIS DESIGN IS PRESENTED.

ACPWS

THE ACPWS CONSISTS OF FLEXIBLE POISON WIRES, RETAINERS, POISON WIRE EXTENSIONS, AND PULL PLATE.

POISON WIRE (910E186)

THE POISON WIRE CONSISTS OF $B_4^{10}C$ BEADS STRUNG ON A TITANIUM WIRE AND ENCLOSED IN A TEFLON SHEATH.

POISON WIRE RETAINER (929F019) (939J634)

A SPRING LOADED RETAINER RESISTS "G" FORCES ANTICIPATED DURING GROUND HANDLING AND ROCKET BOOST, AND IT RESISTS THE FORCES IMPOSED UPON THE INSERTED POISON WIRES DURING A COLD FLOW TEST. THE AFT END OF THE POISON WIRES WILL BE ATTACHED TO THE RETAINERS.

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- DESIGN DESCRIPTION

DESIGNATION

POISON WIRE EXTENSION AND
PULL PLATE

DESCRIPTION

IN THE FLIGHT SYSTEM EACH POISON WIRE RETAINER WILL HAVE A WIRE EXTENDING TO A PULL PLATE LOCATED NEAR THE THROAT OF THE NOZZLE. DURING FLIGHT THE ACPWS EJECTION SYSTEM, MOUNTED IN THE NOZZLE, WILL RETRACT THE PULL PLATE WHICH IN TURN WILL WITHDRAW ALL THE POISON WIRES FROM THE CORE.

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ANTICRITICALITY POISON WIRE SYSTEM

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**POISON WIRE
ASSEMBLY**

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POISON WIRE RETAINER

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POISON WIRE RETAINER

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ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- ANALYSIS OF DESIGN

STRUCTURAL ANALYSIS (PRELIMINARY)

1. FLEXIBLE POISON WIRE
2. POISON WIRE RETAINER

THERMAL AND FLUID FLOW ANALYSIS (PRELIMINARY)

1. POTENTIAL DAMAGE TO FUEL ELEMENT COOLANT CHANNEL

RADIATION ANALYSIS (PRELIMINARY)

1. SPACE RADIATION

NUCLEAR ANALYSIS (PRELIMINARY)

1. FLOODED (WATER) SHUTDOWN CALCULATIONS
2. DRY SHUTDOWN CALCULATION

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- RECOMMENDED DESIGN APPROACH FOR NERVA I

IT IS RECOMMENDED THAT THE DESIGN PROCEED WITH THE DEVELOPMENT OF FLEXIBLE WIRES WITH SINTERED BEADS CONTAINING BORON HIGHLY ENRICHED IN THE B¹⁰ ISOTOPE (DRAWING 910E186).

IT IS RECOMMENDED THAT A POISON WIRE RETAINER BE DEVELOPED WHICH INCORPORATES FEATURES DESIGNED TO ACHIEVE ADEQUATE RETENTION CAPABILITY COMPATIBLE WITH EJECTION FORCE REQUIREMENTS WHILE MINIMIZING LOADS APPLIED TO CHESH.

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

● TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
BEND RADIUS 3.1.1.2.1	POISON WIRES SUBJECTED TO REVERSE BENDING CYCLES ABOUT A 5 INCH RADIUS IN A HYDROGEN ATMOSPHERE.	J1.01	J1.01	J1.01
FRICTION 3.1.1.2.2	PULL TESTS TO DETERMINE STATIC AND DYNAMIC FRICTIONAL COEFFICIENTS FOR POISON WIRES.	J1.01	J1.01	J1.01
CORROSION RESISTANCE 3.1.1.2.3	IMMERSE POISON WIRES IN OCEAN WATER SOLUTION FOR SELECTED TIME PERIOD AND EVALUATE CORROSIVE EFFECT.	J1.05	J1.05	J1.05
OPERATING ENVIRONMENT 3.1.2.4.1	POISON WIRE SPECIMENS SOAKED IN A VACUUM ENVIRONMENT FOR A SELECTED PERIOD OF TIME.		J3.01	
TRANSPORTABILITY 3.1.2.5	SHOCK, VIBRATION AND ACOUSTIC TESTS WITH POISON WIRES IN A FUEL CLUSTER. ALSO TESTED IN POISON WIRE SHIPPING CONTAINER.	J2.02	J2.02	J2.02

ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

● TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
POSITIVE SHUTDOWN 3.1.1.1.1	STANDARD REACTIVITY WORTH MEASUREMENTS OF POISON WIRES PERFORMED IN CRITICAL ASSEMBLY.	W 1.1		W 1.1
POISON WIRE RETENTION 3.1.1.1.2	POISON WIRE IN FUEL ELEMENT SUBJECTED TO DYNAMIC ENVIRONMENT.	J2.01	J2.01	J2.01
POISON WIRE AND CLUSTER INTERACTION 3.1.1.1.3	INSERTION INTO AND EXTRACTION OF POISON WIRES FROM CLUSTER ASSEMBLIES USING VARIOUS ANGLES, RATES, AND SHEATH MATERIALS.	J3.01	J3.01	J3.01
	CORROSION TEST OF CLUSTER ASSEMBLY FROM EML DEVELOPMENT TESTS.	T-3.001	T-3.001	T-4.001
HIGH TEMPERATURE CAPABILITY 3.1.1.1.4	POISON WIRE INSTALLED FUEL ELEMENT AND SUBJECTED TO 1475° F FOR 30 MIN. TEST ALSO PERFORMED IN AIR.	J 1.04	J 1.04	J 1.04
	REACTIVITY WORTH TESTS USING POISON WIRES FROM HIGH TEMPERATURE TESTS.	W 1.2		W 1.2

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ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

● TEST SUMMARY

<u>ECC REQUIREMENT</u>	<u>TEST DESCRIPTION</u>	<u>DEV.</u>	<u>PREQUAL.</u>	<u>QUAL.</u>
MOISTURE AND FUNGUS RESISTANCE 3.3.5	COMPONENT PARTS PLACED IN ENVIRONMENTS THAT SUPPORT THE GROWTH OF VARIOUS TYPES OF FUNGI.	J9.01		J9.01
CORROSION OF PARTS 3.3.6	MATERIALS WILL BE SUBJECTED TO THE ENVIRONMENTS TO WHICH THE REACTOR WILL BE EXPOSED.	J3.02	J3.02	J3.02
STORAGE 3.3.1.1	COMPONENTS WILL BE SUBJECTED TO ANTICIPATED STORAGE ENVIRONMENT AND INSPECTED PERIODICALLY.	J3.03	J3.03	

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ANTI-CRITICALITY POISON WIRE SYSTEM (ACPWS)

- SUMMARY

1. FLEXIBLE POISON WIRES CONTAINING ENRICHED BORON CARBIDE WILL MAINTAIN THE CORE SUBCRITICAL IN BOTH DRY AND FLOODED CONDITIONS.
2. A MINIMUM OF 1878 POISON WIRES WILL BE REQUIRED FOR THE FLOODED CONDITION, AND APPROXIMATELY 260 POISON WIRES WILL BE REQUIRED FOR THE DRY CONDITION.
3. THE RECOMMENDED DESIGN APPROACH WILL SATISFY ALL OF THE PROBLEMS NORMALLY ASSOCIATED WITH MAINTAINING THE REACTOR SUBCRITICAL DURING GROUND HANDLING, ACCEPTANCE TESTING, LAUNCH, AND FLIGHT PHASE PRIOR TO NUCLEAR STAGE OPERATION.
4. A TEST PROGRAM WILL BE CONDUCTED TO VERIFY THAT THE ACPWS WILL MEET ALL ITS REQUIREMENTS.

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RECOMMENDED NERVA REACTOR DESIGN

ECC TITLE

RECOMMENDED DESIGN

1. CLUSTER ASSEMBLY AND MISCELLANEOUS
HARDWARE

COLD END SECONDARY SUPPORT WITH
STANDOFF FROM AFT END HARDWARE.

2. SUPPORT STEM ASSEMBLY

STRAIGHT-THROUGH STEM

3. CLUSTER HOT END SUPPORT HARDWARE

PEDESTAL SUPPORT THROUGH THE
CENTRAL ELEMENT WITH FUEL ELEMENT
STANDOFF, BACKUP DESIGN WITH
GATHERED HOLE KEYED FUEL ELEMENT.

4. FUEL ELEMENTS

1) LOW EXPANSION, LOW VOID, NO
ADDITIVES -- NbC - GEM, GED COATINGS.
2) ZIRCONIUM CARBIDE COATINGS.
3) DEVELOPMENT OF HIGH EXPANSION
FUEL.

5. CORE PERIPHERY

COLD FILLER STRIP DESIGN AND A
0.155 INCH PYROFOIL WRAPPER.

SUMMARY - RECOMMENDED NERVA REACTOR DESIGN - PAGE 2

ECC TITLE

RECOMMENDED DESIGN

6. LATERAL SUPPORT SYSTEM

ANGLE SEAL SEGMENTS

7. REFLECTOR AND AXIAL SUPPORT SYSTEM

RINGS WITH RADIAL SLOTS WITH
CONTINUED EFFORT ON ALTERNATE
DESIGN FEATURES.

8. GANGED DRUM DRIVE SYSTEM

GANGED DRUM DRIVE SYSTEM SUPPORTED
INDEPENDENT OF REFLECTOR AND
LOCATED FORWARD OF THE EXTENSION
SHIELD.

9. SUPPORT STEM FEED AND
DISCHARGE SYSTEM

COMBINED SUPPORT PLATE AND
PLENUM FEED.

10. SHIELDS

CENTRAL SHIELD LOCATED ABOVE THE
SUPPORT PLATE, GANGED DRIVE MECHA-
NISM LOCATED ABOVE THE EXTENSION
SHIELD, AND PROVISION FOR ADJUSTING
THE THICKNESS OF THE CENTRAL AND
EXTENSION SHIELDS AND THE ADDITION
OF SIDE SHIELD, IF REQUIRED FOR
MANNED APPLICATIONS. PROVISION SHALL
BE MADE FOR ATTACHING BORAL LINERS
AROUND THE DOME AND AROUND THE
PERIPHERY OF THE REFLECTOR AS REQUIRED.

11. ANTI-CRITICALITY POISON WIRES

FLEXIBLE WIRES CONTAINING
SINTERED BEADS.

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R/E-1 REACTOR

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R/E-1 REACTOR

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R/E-1 REACTOR

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SUMMARY

PROGRESSION OF DESIGN EFFORT

1. PROCEED WITH PRELIMINARY DESIGN OF REACTOR BASED ON RECOMMENDED DESIGN AND INCORPORATING COMMENTS FROM THIS MEETING.
2. DURING THIS PRELIMINARY DESIGN, DEVELOP PROCEDURES FOR "DESIGNING FOR RELIABILITY" AND PREPARE EXAMPLE AREAS FOR EARLY VISIBILITY.
3. EVALUATE RECOMMENDED DESIGN CHARACTERISTICS AND DETERMINE IF ASSEMBLY SHIMMABLE ORIFICE SYSTEM FOR SSCV IS ADEQUATE.
4. EVALUATE DESIGNING TO ACCOMMODATE HIGH EXPANSION FUEL AND MAKE RECOMMENDATION.
5. EVALUATE REQUIREMENTS OF THRUST SPOILING, SHIELDING, TOPPING CYCLE AND GANGED DRIVE MAINTENANCE AND INPUT AS REQUIRED INTO MAIN STREAM EFFORT.

STRUCTURAL SUPPORT COOLANT SUPPLY SYSTEM

I. INTRODUCTION

(CRD) The NERVA reactor incorporates a core axial support system which provides channeling for the passage of hydrogen through the support system. The subject SSCSS is the means by which the hydrogen flow to the support system is delivered and controlled. The vu-graph now seen is a simple line diagram of the SSCSS. The system consists of a valve and its actuator along with the related piping and supports required between the turbo-pump and forward closure.

The SSCSS is defined in the NSS-CEI as a contract end item which will be installed within the NSS.

The CEI Specification Document, CP-677575, has been released for review in draft form. Since the time of issuance, analyses have been completed which dictate several specification changes. This presentation is consistent with the values associated with the reference reactor design.

II. REQUIREMENTS

(U) By AFSCM Manual Guidelines, the capabilities of the CEI are defined in the category of Performance Requirements. A brief description of these significant requirements are listed in this vu-graph. Those items which appear on the left are the design requirements with the corresponding "basis" of each listed requirement listed on the right.

III. DESIGN SOLUTION

(U) A concept of a design solution to those requirements which we just presented is the subject of the next vu-graph. This system concept consists of an actuator and a valve with one inlet port, and two outlet ports. In the CEI, this solution is defined as two ECC's.

- 1) SSCV Actuator
- 2) SSCSS Valve, Piping and Supports

- (U) The valve, piping and support will be designed and fabricated by AGC. The overall system and the actuator are WANL design responsibilities.

Other systems considered were two valves and two actuators or one actuator driving two valves, but it is believed that the reliability requirements can be met with the concept presented. No detail reliability study has been made to date such as definition of failure modes and therefore, redundancy needs have not been completely defined as yet.

IV. TEST PROGRAM

- (U) The test program to formally verify the SSCSS requirements is specified in the CEI document. Developmental tests will not be accomplished at the CEI level. All developmental tests are specified to be performed at the ECC level. The Formal CEI Qualification Testing Program consists of (1) a full scale SSCSS assembly tested at the AGC Sacto hydrogen facility, and (2) further qualification by analyses, inspection, and demonstration. It is also planned that, whenever possible, qualification will be accomplished at the ECC level.

The full scale SSCSS test program presented on this vu-graph lists the specific requirements which are to be qualified and the method by which the verification will be accomplished.

As mentioned previously, in addition to the full scale SSCSS hydrogen test, qualification will be based upon analyses, inspection, and demonstration. The requirements qualified by this mode of verification will be non-operating requirements such as weight, interface, and workmanship.

In summation, the status of the SSCSS is this:

- 1) The CEI document has been issued in draft form.
- 2) A design concept is presently being analyzed for application as the SSCSS solution.
- 3) A complete set of design requirements with a formal test program are formulated to be implemented in the program.

STRUCTURAL SUPPORT COOLANT SUPPLY SYSTEM (SSCSS)

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STRUCTURAL SUPPORT COOLANT SUPPLY SYSTEM

PERFORMANCE REQUIREMENTS

Requirement

Basis

Provide constant flow of 21 lb/sec at rated conditions.

Constant nozzle bypass simplifies system design. 21 lb/sec provides sufficient SSCSS bypass flow to moderate stem effluent prior to mixing with reflector outlet flow.

Adjustable output flow capability at rated condition over a range of

At rated conditions, the coolant flow range corresponds to stem material temperature limits of 1000°R and 250°R respectively. Flow adjustment required for reactivity shimming.

- a) Coolant flow, 5.3 to 10.0 lb/sec
- b) Bypass flow, the difference between the input and coolant flow

Provide a constant rate of change of flow for each demand signal level.

Simplifies control.

Respond to a demand signal within T. B. D. seconds.

System response must satisfy SSCV position requirements during certain NSS shutdown transients.

The pressure drop from SSCSS inlet to SSCSS coolant outlet shall not exceed 10 psid at full flow.

Low ΔP is required to exploit the available stem coolant driving head (maximizing reactivity swing). 10 psid requests a practical minimum pressure loss for the system.

External leak rate shall not exceed 10^{-2} scc/sec of hydrogen per inch of seal diameter.

Required to meet the PRD specifications.

SSCSS reliability goal of 0.99992 based on ability to satisfy performance requirements.

This goal represents the apportioned reliability based on an NSS reliability of .997 of meeting mission success.

DESIGN CONCEPT STRUCTURAL SUPPORT COOLANT SUPPLY SYSTEM (SSCSS)

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FULL SCALE SSCSS
QUALIFICATION TEST PROGRAM*

<u>Qualification</u>	<u>Method</u>
1. Performance Characteristics	Full scale SSCSS test at the AGC Sacramento H ₂ facilities using H ₂ at operating temperatures and pressures.
A. Constant Input Flow	
B. Two System Output Flow	Perform tests and measure flow data for conditions of pressure, temperature, and reactor impedance.
C. Flow Characteristics	
D. Flow Rate of Change	
E. Response	
2. Radiation Environment	Qualification testing will be by reason of conducting R-1 reactor tests at NRDS.

* Tests other than those listed will be performed at the component (ECC) level.

SSCV ACTUATOR

I. INTRODUCTION

- (U) The Structural Support Coolant Valve Actuator is one of two ECC's which are defined within the SSCSS-CEI document, CP-677575. As mentioned in the SSCSS presentation, there has been some recent analysis completed since issuance of the documents in draft form. This presentation of the SSCV Actuator will, however, be based upon the current design information.

II. REQUIREMENTS

- (U) In keeping with the guidelines established by AFSCM 375-1, the "design to" requirements or capabilities of the actuator are expressed in terms of performance requirements. The vu-graph which is now presented contains a brief verbal description of each of the performance requirements with an appropriate corresponding statement as to the technical basis for each requirement.

In regard to the requirement for allowable consumption rates, the reference flow as stated in the SSCSS Specification is, "Routing a portion of the SSCSS main stream hydrogen flow through a component portion of the SSCSS is permissible provided that paragraphs 3. 1. 1 and 3. 1. 2 are satisfied." The referenced paragraphs, 3. 1. 1 and 3. 1. 2, specify "functional characteristics and operability" of the SSCSS. Therefore, it suffices to say that any value of actuator coolant consumption rate is allowed which does not prevent the system meeting the "design to" specifications of the SSCSS.

III. DESIGN CONCEPTS

- (U) A concept of an actuator-valve interface is presented on the following vu-graph. Those features which are presented as hardware type concepts are: 1) use a V-Band coupling to accomplish mounting of the actuator to the valve; 2) use of a chevron type seal as the interface sealing element; 3) splitting of the seal groove into each interface half; and 4) mechanically coupling the input-output shafts by means of a serrated spline. The chevron seal, splitting of seal grooves, and V-Clamp flanging arrangement as shown are based upon

XE control drum actuator experiences. The seals are proven devices of the XE control drum actuator. The seal grooves are halved to protect sealing surfaces, and the V-Band clamp is the same method tested and proved for XE actuator-pedestal interfacing. The serrated spline is specified as a means to allow for expansion and contraction of the mating parts which is expected to occur due to the induced temperature ranges experienced from H_2 flow and nuclear heating. In addition, the specified method is a rather simple, reliable, proven coupling method.

(U) The engineering approach taken to provide a highly reliable design which will satisfy the requirements of the ECC document was to first locate the most suitable actuator presently on the market which was developed and could readily be applied, and second, upgrade or modify this selected unit if required. In the event no actuator could be found, then an actuator design would be undertaken. Actuators from: 1) our own actuator program, 2) other Government programs, and 3) the existing commercial field were considered. The initial phase of this approach was to compare those types of actuators which could be used for the operation. The comparison is presented on this vu-graph. Since the system is best suited for application of a simple open loop control mode, the selection of actuator types was influenced on this basis. The selection however did not eliminate the GE or Bendix pneumatic actuators as candidates but did cause us to direct our attention primarily to other listed types. The next phase in this engineering approach was to contact manufacturers of these types of actuators to determine who had units developed which would apply. This "Search and Survey" was conducted with the emphasis placed mainly upon torque, speed, and environmental capabilities. This next vu-graph summarizes the 25 contacts made in the commercial market and/or Government programs.

(U) The result of the search and survey was the finding of two (2) new actuator candidates. These are: 1) the Bendix Dynavector, and 2) the Rocketdyne J-2 Engine PUCV Actuator. This vu-graph presents a comparison of all four actuators which were considered from the overall effort. Of these four actuators, the Rocketdyne actuator is proposed as the prime candidate. This actuator was one of the types desired on the basis of the first comparison. The factors which influenced the final selection are: 1) the unit is capable of simple open loop operation,

2) it can be upgraded to the functional requirements required with a minimum or redesign, 3) the unit has an extensive documented history, 4) within the J-2 engine program, it has been fully qualified to low temperature, high temperature and storage at 140°R, vibration (50g and 2000 cps), sand and dust, ignition and explosion proof per MIL-E-5272C, altitude 1.52×10^{-2} mm Hg and endurance. One hundred fifty (150) qualified units have an accumulated operating time of nearly 4000 hours of J-2 engine testing.

The next vu-graph presents a cutaway view of the prime candidate actuator.

(U) In a continuing effort of the plan adapted in selecting an actuator, a development test program is implemented. The selected prime candidate actuator will be tested to this development program. In addition, those alternate actuators having a potential of satisfying the performance requirements will also be tested in a parallel effort. The development test program is listed on the next vu-graph.

IV. QUALIFICATION TESTS PROGRAM

(U) Once a final actuator is re-designed if necessary and purchased to the ECC Specification, the actuator shall be formally tested and qualified. This formal qualification testing is delineated in the actuator ECC document and displayed visually on this vu-graph. Those requirements to be formally qualified are listed under the heading "Formal Qualification." The method used in verifying each requirement is listed under the title, "Method." The methods of verification to be used per AFSCM 375-1 are Inspection, Analyses, Demonstration, and Test. There are 14 requirements listed which are to be formally verified by Inspection. There are 4 requirements which are listed for verification by Analyses. The radiation portion of the environmental requirement will be qualified only by analysis prior to R-1 testing. Those requirements of Service and Access, Transportability and Maintainability will be verified by demonstrations. The vast majority of the specifications which are the capability requirements of the actuator will be verified by actual tests as conducted at WANL. These tests will include shock, vibration and low temperatures with operational and performance measurements during induced operating environment. Reliability, excluding radiation, shall be formally verified by tests and analysis. At the present time, no explicit or detailed reliability tests

are specified because until a final design is achieved, the exact failure mode analysis can not be made. Through the entire course of design, redesign, and evaluation, the specified reliability goals are prime factors considered in this engineering approach.

V. SUMMARY

(U) In summation, it is felt that by utilizing an actuator which approximates the NERVA requirements and has a proven history of successful operation, we can assure ourselves of a design which will meet reliability goals. In pursuit of this approach, an extensive search was made and a candidate selected. In parallel, other units with favorable histories are being analyzed. Unless a change from the selection is dictated in further tests, analyses, or developments, the J-2 actuator will be subjected to the development test program, redesigned as required, and contracted to the ECC document.

SSCV ACTUATOR PERFORMANCE REQUIREMENTS

<u>Requirement</u>	<u>Basis</u>
Maintain a fixed output shaft position withstanding SSCV torque loads to 500 inch-pounds maximum.	500 inch-pound torque load is the specified valve load limit. Once the system satisfies the reactor control demand, then it must hold that position until a new demand is received.
Satisfy all operating requirements against full operating torque loads for either direction of SSCV shaft rotation.	Required to meet bi-directional flow control per SSCSS Specification CP-677575.
Attain a commanded output shaft position to within ± 0.5 degree over the full travel range with repeatability to within ± 0.5 degrees at full operating loads.	The requirement is necessary to provide a small enough error band to prevent over travel or inaccuracies which will cause excessive jogging of the actuator or reactor control loop system hunting.
Speed-torque characteristics - Speed range of T. B. D. $^{\circ}$ /second as a function of input voltage against torque load of 500 inch-pounds. The regulation of this speed for loads between 0 and 500 inch-pounds shall not exceed 10% for any constant input voltage required to attain T. B. D. $^{\circ}$ /sec.	This requirement is intended to meet the SSCSS-CEI requirements whereby the actuator is to move a valve fast enough to meet off design conditions of startup and shutdown. Also, to meet speeds slow enough to shim the reactor. This must be accomplished over the range of valve torque loads.
Respond to a command signal to achieve T. B. D. $^{\circ}$ /second within T. B. D. seconds in either direction against loads from 0 to 500 inch-pounds.	Required to meet Specification CP-677575 which delineates an overall SSCSS response.
Consumption Rates Allowed: Coolant Flow (Actuator) = CP677575 Electrical Power = 20 Watts Pneumatic Power (H_2) = 0.015 lb/sec (100 $^{\circ}$ R)	The coolant flow consumption allowed for actuator coolant purposes is defined per SSCSS Specification CP-677575. The electrical power consumption is limited per WANL design limits based upon loads of 500 inch-pounds and other performance requirements. The pneumatic power consumption is based upon the XE series control drum actuator rates.
Position Indication - An electrical feedback signal analogous to actuator shaft position at the SSCV input shaft.	Required as diagnostic instrumentation so as to have a means available to relate position to flow which is a performance parameter.
Positions stops limiting the SSCV travel at 0 $^{\circ}$ and at an adjustable point between 90 $^{\circ}$ and 300 $^{\circ}$. Must be capable to withstand combined inertia and torque loads.	This requirement is stated such so that <ol style="list-style-type: none"> 1) In event of failure the 0° stop will be located to provide the required minimum flow value in order that adequate cooling will always be provided and 2) An adjustable stop between 90° and 300° is required so that for any changes of turbo-pump state point the maximum flow rate can be achieved by stop manipulation 3) Stops are located in actuator to take advantage of the low inertia loads.

① Valve Housing	⑤ Valve Drive Shaft
② V-Band Clamp	⑥ Seal Groove Halves
③ Actuator Housing	⑦ Chevron Seal
④ Actuator Drive Shaft	⑧ Serrated Spline

ACTUATOR VALVE INTERFACE

(Concept Only)

COMPARISON OF ACTUATOR TYPES

ACTUATOR TYPE		OUTPUT SPEED	LOW TEMPERATURE OPERATION	RADIATION RESISTANCE	ENERGY CONSUMPTION	LOOP OPERATION	ASSOCIATED ELECTRONIC COMPLEXITY
GE PNEUMATIC	SIMILAR TO XE-SERIES CONTROL DRUM ACTUATOR	TOO HIGH ADD CONSTRICTION	SATISFACTORY	SATISFACTORY	CONTINUOUS	CLOSED LOOP	COMPLEX
BENDIX PNEUMATIC	SIMILAR TO XE-SERIES TPCV ACTUATOR	TOO HIGH ADD CONSTRICTION	TESTS PERFORMED TO BE EVALUATED	SATISFACTORY	CONTINUOUS	CLOSED LOOP	COMPLEX
ELECTRIC STEPPER	OPERATED WITH A LARGE GEAR REDUCTION	SATISFACTORY	NOT PROVEN NO PROBLEMS ANTICIPATED	SATISFACTORY SNAP 50 2000 HR AT 10^{19} NVT SNAP 10 A 5×10^{18} NVT 5.5×10^9 R	INTERMITTENT AS REQUIRED	OPEN LOOP	COMPLEX
PNEUMATIC TURBINE	OPERATED WITH A LARGE GEAR REDUCTION	SATISFACTORY	NOT PROVEN NO PROBLEMS ANTICIPATED	UNPROVEN BUT NO PROBLEMS ANTICIPATED	INTERMITTENT AS REQUIRED	OPEN LOOP	SIMPLE SOLENOID
PNEUMATIC STEPPERS	OPERATED WITH A LARGE GEAR REDUCTION	SATISFACTORY	NOT PROVEN NO PROBLEMS ANTICIPATED	UNPROVEN BUT NO PROBLEMS ANTICIPATED	INTERMITTENT AS REQUIRED	OPEN LOOP	SIMPLE SOLENOID
INDUCTION MOTOR	OPERATED WITH A LARGE GEAR REDUCTION	SATISFACTORY	NOT PROVEN NO PROBLEMS ANTICIPATED	UNPROVEN BUT SIMILAR TO ELECTRIC STEPPER	INTERMITTENT AS REQUIRED	OPEN LOOP	SIMPLE + INVERTER
D. C. MOTOR	OPERATED WITH A LARGE GEAR REDUCTION	SATISFACTORY	NOT PROVEN NO PROBLEMS ANTICIPATED	UNPROVEN BUT SIMILAR TO ELECTRIC STEPPER	INTERMITTENT AS REQUIRED	OPEN LOOP	SIMPLE ELECTRICAL SWITCH

SSCSS ACTUATOR

SEARCH AND SURVEY

<u>Company</u>	<u>Actuator</u>	<u>Type</u>	<u>Remarks</u>
Superior Electric	Stepper Motor	Electric	Would require development program.
Bendix Corporation	Dynavector TM	Pneumatic	Would require development program.
Gaylord - Rives	Servo & Stepper	Electric	Capable of developing servo motor.
SNPO-C	Any Candidate	Any	Contacted Al Hintze for names, aid.
Pratt-Whitney	Any Candidate	Any	Talked to Dr. Strough, Ref: SNAP-50.
Unite-Shoe	Responsyn TM	Electric	Would have to be developed.
Photo-Electronics	Stepper Motor	Electric	Not Applicable (Uni-directional).
General Electric	Servo - Stepper	Electric	Several tries - no response.
Char-Lynn	Motor	Pneumatic	Bought one (1) unit to evaluate.
Con Rac, Cramer Division	Stepper Motor	Electric	No application.
Avionics Division (Cramer)	Stepper Motor	Electric	No positive response.
Fluid Drive Engr.	Stepper Motor	Electric	No positive response.
Muirhead Instr.	Stepper Motor	Electric	No application.
Wright Machinery	Stepper Motor	Electric	Referred to Sperry Rand.
Sperry Rand	Stepper Motor	Electric	Referred to Sigma.
Sigma Instruments	Stepper Motor	Electric	No application, claim could develop.
Kearfott Aerospace	Servo - Stepper	Electric	Sent Requisition - negative response.
American Electronics	Stepper	Electric	No response.
Bowmar Instruments	Servo - Stepper	Electric	No response.
Holtzer-Cabot	Servo - Stepper	Electric	No response.
Redstone Arsenal	Any	Any	Lead on J-2 Lox Valve Actuator.
Rocketdyne	Lox Actuator	Electric	Very good candidate - good response.
WANL	Candidates	Any	Information from Technical Utilization Program.
University of Santa Clara	Stepper Motor	Electric	Obtained paper, Ref: Surveyor Spacecraft.
Gast Manufacturing	Air Motor	Pneumatic	Generally industrial types.

COMPARISON OF ACTUATOR CANDIDATES

Candidate	Type	Loop Operation	Speed	Energy Consumption	Radiation Resistance	Low Temperature
XE Control Drum	Pneumatic	Closed	Too High	Continuous	Satisfactory	Satisfactory
TPCV (XE Series)	Pneumatic	Closed	Too High	Continuous	Satisfactory	Tested
Bendix Dynavector	Pneumatic	Open	Satisfactory	Intermittent	Unproven	Not Proven
J-2 Engine PUV	Electric	Open	Satisfactory	Intermittent	Unproven	Satisfactory

Candidate	Electronic Controls	Dynamic Environment	Past Performance History	Require Redesign
XF Control Drum	Complex	Tested	Good - XE Series	Yes
TPCV (XE Series)	Complex	Tested	Good - XE Series	Yes
Bendix Dynavector	Complex	No Data	No History	Initial Design
J-2 Engine PUV	Simple	Tested	Good - J2 Engine	Yes

ALTERNATIVE APPROACHES TO REDUNDANCY

1. Passive Logic
2. Active Logic
3. Computer Supervised Redundancy

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REACTOR CONTROL SYSTEM PRESENTATION
AT THE
ENGINEERING DATA AND CONCEPTS MEETING

- (U) In this presentation on the Reactor Control Systems, I will discuss performance requirements, design concepts and development testing. The reactor control system as defined by ECC-677568 consists of those systems which regulate reactivity thru drum movement or support structure flow, reactor safety systems and the system which regulates the removal of decay heat.
- (U) Comments by AGC on the first draft of the ECC have not yet been factored into our analysis. Additionally, neither AGC or the Government specialists have yet had an opportunity to review the design concepts in detail.
- (U) Vu-Graph No. 1 lists the major performance requirements. The first requirement is on static accuracy of reactor temperature control. The figure $\pm 50^\circ$ is a preliminary allocation of the controls portion of the 3/4% accuracy requirement on I_{sp} specified in the PRD.
- (U) Vu-Graph No. 2 shows the principle source of error in the temperature control system. It indicates that the errors in thermocouple and signal conditioning are not to be considered part of this $\pm 50^\circ$, that the control system error consists of the cumulative errors in averaging and in the input networks to the controller and the type of control. The small value of allowable error indicates an integral type of control leaving averaging and input resistors as the source of the $\pm 50^\circ$ error. An additional inaccuracy of $\pm 50^\circ$ is specified for the control-thermocouple plus measurement errors due to the fact that the thermocouples may not see properly mixed gas. This latter error may be as much as a few hundred degrees. Further analysis is required to specify limits on this source of error.
- (U) The second requirement shown on Vu-Graph No. 1 is on startup rate. It specifies 150°R/sec rate of change of reactor temperature and 50 psi/sec rate of change of chamber pressure. These requirements are specified in the PRD. Trade-off studies are being performed which will illustrate the penalties that we must pay to meet these high rates vs the benefits to be obtained. I feel that we have control concepts that probably can handle these high rates.

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(CRD) The third requirement is on reactor autostart. It is based on the PRD missions, specifically, sub-orbital start in which 200 seconds is available to start up the reactor prior to staging. The fourth requirement specifies a flexible approach to a safety system which would permit partial mission completion or partial thrust despite failures as specified in the PRD. The PRD specifies that the decay heat which occurs after reactor shutdown should be removed at the highest possible I_{sp} . Our preliminary analysis shows that 1500°R is a structural limit; hence, the fifth requirement of decay heat removal at 1500°R . A nuclear power control system is necessary to handle requirements for reactor operation at power levels at which sensible heat is not generated. Such operation includes low power checkout at NRDS, cold flow acceptance testing as specified by the PRD, and possible checkout in space. The Structural Support Coolant Valve will be used to shim the drums to a reference angle specified by the reactor designers. This shimming control is needed to satisfy the NSS endurance requirements in the PRD. The relationship between shimming and corrosion has been developed in L. Boman's presentation. In addition to its shimming function, the SSCV may require rapid movement to control its coolant flow. Further studies are required on this subject.

(U) One of the major topics of this presentation will be the reliability requirements and how we propose to satisfy them. But before considering the reliability requirements specified in the PRD, let's consider the components that make up a reliability requirement, in order to get a better feel for why these requirements dictate an extrapolation in the state of the art.

(U) The next vu-graph shows an exponential relationship which we can call the reliability law. This law says that reliability is exponentially related to the ratio of mission time to mean time between failure. It implies that in specifying reliability one must specify a probability of failure that one must define failure and that the mission must be specified in order to get the time. The curve shown on this vu-graph is a plot of the reliability law. It illustrates the fact that as time becomes very large, reliability becomes very small. On the next vu-graph, the NERVA reactor control system reliability goal is broken into these components. Failure is defined as a control system malfunction which interferes with normal nuclear subsystem operation or interrupts the mission. The probability of no such failures is specified as .99989. This number is based on

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the PRD requirement of .995 as applied to total system reliability and is apportioned by fault tree analysis of the NERVA system. The duration of this specified reliability is two years after pre-launch checkout. This is based on the PRD requirement for one year storage in space prior to the first burn and 30 days between subsequent operations.

- (U) These requirements may seem fairly innocuous, but they are drastic changes from requirements on control systems used in the technology development program, specifically in the areas of speed of responses and reliability. We think we have design solutions or at least design approaches that will lead to solutions to these problems. They are summarized in a system print, 710J244, which is available for your examination. It is too detailed to use as a visual aid, but you are welcome to examine it later.
- (U) The next vu-graph is an outline of this system print in block diagram form. The details will be shown on individual subsystem vu-graphs.
- (U) The block diagram shows alternative control modes based on either a nuclear power feedback or a temperature feedback. Since there is no requirement to switch from one of these to the other, on-line mode switching is not provided and the choice is made prior to reactor operation. Each of these systems has its own autostart subsystem and its own manual drum position control subsystem. The controller provides an input to the control drum system which varies reactivity. The support structure coolant valve control system is shown with an input from drum shimming control which uses average actuator position as a feedback. It also has inputs from a Reactor Safety and Diagnostic System and a malfunction recovery control mode which we will discuss in detail later.
- (U) Vu-Graph No. 10 is a schematic of a temperature controller which shows promise of satisfying the NERVA requirements. We are currently investigating the characteristics of this controller and have some data which I will show in the next two vu-graphs. It is a three mode controller in that it utilizes a low gain integral term to provide the required high static accuracy, a proportional term to provide good response for minor transients which require less than 15° of drum movement, and an on-off term which shifts the proportional band for major transients which require gross drum movement. This non-linear approach is required to utilize the non-

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linear characteristics of the NERVA pneumatic actuator. Further development will be required to specify the precise control system configuration, but we feel that the final NERVA reactor controller will be some variation of the on-off control concept if a high performance system is to be developed utilizing the pneumatic actuator.

(U) Vu-Graph No. 11 comes from analog computer data taken during a simulated high impulse startup. It shows that the hybrid temperature controller will program the reactor at $150^{\circ}\text{R}/\text{sec}$ and that it minimizes large temperature overshoots induced by the 50 psia/sec pressure ramp. We feel that further development will minimize the erratic drum motion shown during this transient.

(U) Vu-Graph No. 12 is similar analog data for a high thrust startup. This high thrust startup is considerably easier to perform than the high I_{sp} startup because the rapid increase in chamber pressure occurs at a lower temperature where you are not nearly so concerned with overshoots. In the particular transient shown, the rate of change of chamber pressure is decreased prior to reaching design temperature in order to minimize this overshoot. Obviously, the position of the knee on this curve can be optimized.

(U) Vu-Graph No. 13 shows how we can integrate a simple autostart scheme into the hybrid temperature controller. In the technology development program, autostart has been accomplished by programming control drum position in a pre-determined, arbitrary manner until the controller feedback variable (power or temperature) reaches a pre-set limit. Such a concept can not be directly applied to a NERVA flight system because of large uncertainties in the critical drum position. Even on the first startup, after a critical experiment on the ground, the critical position during the sub-orbital start will not be known with precision. One approach to solving this problem would be to compute this critical drum position from all the possible parameters that influence it such as vibration, compaction, solar heat, mission history, corrosion, and cool down status, but a more feasible approach seems to be to try to measure the critical drum position somehow and use this measurement as another feedback to the autostart system. One variable which is a direct measure of critical drum position once the reactor has gone critical is reactor period. The autostart system shown compares

period to a pre-set switching level for instance two seconds and halts drum movement when this two second period is reached. The sequence of events that would take place during an auto-start is as follows. A temperature demand of say, 1000°R would be introduced to the temperature controller. Since the feedback signal indicates a temperature less than 1000°R , the on-off controller would rotate the drums to a more critical position at $5^{\circ}/\text{sec}$. When a two second period was attained, the period switching would inhibit the on-off controller and the drums would stop at a constant super-critical position corresponding to this two second period. When the core material temperature increased due to the steadily increasing power, the temperature error would go to zero and the proportional term in the temperature controller would run the drums in approximately 10° below the critical position. When chilldown is initiated and the gas temperature rises above the particular material temperature being monitored, gas temperature would become the normal feedback selected by the auctioneer. The next slide shows this sequence of events and is based on analog computer data. Drum position is shown changing at around $3^{\circ}/\text{sec}$ in this particular run due to the sudden application of a temperature demand. The drums are stopped in place when a two second period is reached and log power increases at a constant rate until the temperature error changes sign at which time the controller takes the reactor sub-critical until chilldown reduces chamber temperature to the demanded level. We feel that adding an input from nuclear instrumentation to the temperature autostart will result in a predictable, repeatable startup system despite large critical drum position uncertainties.

- (U) The next vu-graph simply indicates that simple integral control is adequate for drum shimming with the SSCV since dynamic requirements are very low and the status accuracy requirements are fairly severe. This controller reduces the theoretical inaccuracies in drum shimming to near zero and allows virtually all the error to be assigned to drum position measurements. If it is necessary to vary valve position to maintain coolant flow, additional logic would be required.
- (U) Vu-Graph No. 16 shows the nuclear power controller. It is intended to be a mirror image of the temperature controller in order to utilize identical logic in position control and

autostart. Performance requirements on this system are minimal since only slow transients are contemplated.

- (U) Vu-Graph No. 17 is a block diagram of the proposed reactor cooldown system in which the reactor control system sends commands to the engine programmer to start and stop coolant pulses. The cooldown requirements themselves are similar to those that have existed throughout the technology development program; however, a new dimension of control is implied by the requirement to maintain the coolant gas at the maximum permissible I_{sp} .
- (U) Vu-Graph No. 18 lists the functions to be performed by the reactor safety and diagnostic system. Perhaps the most important of these functions is reactor control malfunction protection which we will discuss in detail in the next two vu-graphs. The second function is correction for thermocouple degradation. It implies that the functions performed by the test monitors in Test Cell "C" will be automated. The third major function is diagnosis of malfunctions and providing the information required to continue a mission after malfunction. This system will also monitor and report drum misalignment to allow any necessary corrective measures to be taken if a drum should stick. It will also monitor the status of redundant elements and report on overall control system reliability status.
- (U) The next vu-graph shows a typical NRX scram chain in which a reactor parameter such as nuclear power is compared with a fixed, pre-determined setpoint. If this setpoint is exceeded, an irrevocable action, that is scram, takes place. Such a system is not acceptable for NERVA mission because it does not allow for correction of the problem and mission continuation or partial mission success.
- (U) Vu-graph No. 20 shows that portion of the reactor safety and diagnostic system which we are proposing as an alternative to scram. This particular logic sequence provides protection against a failure of the temperature controller. Although the temperature controller includes sufficient redundancy to the reliability requirements, this further protection is required to insure controllability at partial thrust if the inherent redundancy of the temperature controller is overcome. Drum position and temperature error are inputs to a block of flexible logic which determined whether or not they are consistent with each other. That is, any change in drum

position must be the result of a temperature error unless there has been a failure in the reactor control system. This permits very early reaction to a drum movement which is due to a system failure. It is not necessary to wait until the drum has moved several degrees, since any movement at all which is not consistent with temperature error indicates a failure. The reaction of the system to such an inconsistency is to first lock the drums in position and then switch the SSCV to the malfunction recovery control mode. Control of reactivity is then through the SSCV system. If the SSCV is at an extreme position so that it can not control reactivity, another comparison identifies this fact and requires the engine controller to reduce flow until the SSCV comes on range. This system permits continued operation at the highest possible level until the malfunction is automatically diagnosed and information is provided on what steps to take next. This automatic diagnosis again involves a system of flexible logic which looks at all available reactor and controller parameters and isolates the cause of failure.

(U) The next vu-graph shows some more detail on the malfunction recovery mode. It indicates that a nuclear power error operates the SSCV in this malfunction situation. Nuclear power was selected to provide a maximum independence of the normal control schemes and use of the SSCV to vary reactivity provides independence of the control drum system. This control mode will have very poor dynamic performance and will be primarily for steady state operation.

(U) This malfunction recovery mode is the last of the subsystems which we are proposing to satisfy the NERVA requirements and now I would like to get into the techniques which we feel are required to satisfy the reliability requirement.

(U) Vu-Graph No. 22 shows the current state of the reliability art. The ordinate of this curve is the probability of failure of a system; hence, this probability of failure is the reliability compliment of the direction of better performance on this ordinate is down. At the top of the curve, the probability of failure is 1; the worst case. The abscissa is mission time in hours. Gemini was designed to be a two week mission. The apportioned electronics reliability was .97. Mariner was 108 day mission with an apportioned electronics reliability of .91. The multiple mission approach to NERVA design requires a reactor control system reliability of .99989 for a period of two years. It is quite apparent that the NERVA reliability goals require an extrapolation in the state of the art as defined by Gemini and Mariner. In fact, if the NERVA

reactor control system consisted of only a single operational amplifier, that operational amplifier would not meet the NERVA reliability goals. The only answer to this problem is some form of redundancy.

- (U) The next slide is a model of redundancy on which we shall base the rest of the discussion.
- (U) L is the number of series blocks in the reactor control system; n is the number of parallel blocks or the order of redundancy. The logic blocks shown select "good" signal flow paths and reject "bad" ones. Ordinary passive logic is of the "majority voter" type. That is, if n equals 5, three good signals are required for proper operation. Ideal logic would select a good path even if all others are bad.
- (U) Vu-Graph No. 24 shows quantitatively the effects of redundancy utilizing such ideal logic. It assumes each of the individual blocks shown in the redundancy model have a reliability of .9. Then if the serial length L is 1, the case of no redundancy shows a probability of failure of .1. The case of n equals 5 shows a probability of failure 10^{-5} . Tremendous improvements in reliability are theoretically possible through redundancy. A ball park number for the NERVA reactor control system is L equals 10 which suggests at least fifth order redundancy would be required.
- (U) The next vu-graph shows the same curve that we have just seen as solid lines and it shows in dashed lines the reliability improvement obtainable with simple passive logic. It is apparent that much higher order of redundancy is required unless the simple majority voter type logic can be improved on. For seventh order redundancy with passive logic, the probability of failure is two orders worse than with fifth order redundancy and ideal logic. The improvement shown as ideal can be realized through the use of a system of active logic implemented on a digital computer. One simple example of such active logic is the average and reject systems used as temperature averagers in the technology development program.

- (U) Simple passive logic requires a large order of redundancy and therefore a large amount of analog equipment. The second approach, active logic, uses much less analog equipment but does require the use of a digital computer. It suffers from the disadvantage of depending heavily on the reliability of the digital computer. A third approach, which is the one we are proposing for NERVA, combines the passive and active concepts. It uses simple passive logic for on-line switching then a digital computer periodically surveys the system for faulty elements and eliminates their consideration by the majority voters. This scheme idealizes the passive logic. On the other hand, if the digital computer fails, the passive logic still works. Further, on command, the digital computer can survey the redundant elements and tell the crew which should be replaced manually.
- (U) In our current design approach, the techniques of computer supervised redundancy will be applied in sufficient detail to satisfy our reliability goal. Preliminary analyses indicate that fourth order redundancy is probably sufficient to accomplish this. The basic blocks which will be made redundant probably are not individual amplifiers but rather functional units such as temperature controller, demand generator, averager, etc. One redundancy configuration which we have been considering is shown in 100E248. Next month we will have a breadboard system which demonstrates the use of computer supervised redundancy. A redundant temperature controller controlling the R-1 analog model will be supervised by our Raytheon 520 digital computer.
- (U) The last section of this presentation is an outline of our development testing plans. When we test R-1, it will be with a reactor control system which was developed on a simulator. The dynamic accuracy of this simulator will have been backed up with very little test data. Controller performance is highly dependent on model accuracy; therefore, our primary goal in development testing will be to accumulate test data required to improve model accuracy. No specific controls experiments as such are planned for R-1; however, the operational characteristics of the R-1 reactor using the reference design reactor controls will be determined from normal reactor operations. Specific experiments will be performed to measure the dynamic characteristics of the R-1 reactor for model development purposes. With the new model developed from this data, the controls will be redesigned and re-evaluated on R-2. The

second pass will almost certainly be required because the system is so non-linear that extrapolation and interpolation is difficult. Most development testing of control systems will be done on analog models rather than on the test system itself. Since R-2 is to be the pre-qualification test for components of the nuclear subsystem, the intent of the development program is to have, for R-2, a reactor control system which will permit design performance demonstration by the nuclear subsystem.

(U) A number of areas have been identified where severe performance requirements demand extraordinary solutions. We feel that the design approaches presented here will lead to such solutions.

(U) During the next few months prior to PDR, we will be developing these concepts, testing them against alternatives, and preparing specific functional designs for use on R-1, so that the ideas sketched out here can be presented at the PDR in concrete form.

MAJOR PERFORMANCE REQUIREMENTS OF ECC - 677568-A

- a. $\pm 50^{\circ}$ Static Accuracy (Demand - Thermocouple Reading)
- b. Startup Rates of 150° R/sec and 50 psi/sec
- c. Autostart time of 200 seconds
- d. Graduated Responses to Malfunctions to Enhance Mission
Completion Probability
- e. Decay Heat Removal at 1500° R
- f. Nuclear Power Control for Low Power Checkout
- g. Use of SSCV to Shim the Drums to a Reference Angle $\pm 1^{\circ}$

ERRORS WHICH CAN BE MANAGED BY CONTROL DESIGN

SOURCES OF TEMPERATURE CONTROL ERROR

PROBABILITY OF NON-FAILURE IS RELIABILITY

$$R = e^{-\Delta t / \text{MTBF}}$$

RELIABILITY CONCEPTS

RELIABILITY REQUIREMENTS

1. DEFINITION OF FAILURE

A control system malfunction which interferes with normal NSS operation.

2. PROBABILITY OF NO SUCH FAILURES

.99989

3. DURATION OF SPECIFIED RELIABILITY

2 years after pre-launch checkout

BLOCK DIAGRAM
OF
NERVA REACTOR CONTROL SYSTEM

HYBRID TEMPERATURE CONTROLLER
SUBSYSTEM SCHEMATIC

HIGH SPECIFIC IMPULSE STARTUP WITH HYBRID CONTROLLER

HIGH THRUST STARTUP WITH HYBRID CONTROLLER

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HYBRID REACTOR AUTOSTART CONTROLS

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REACTOR COOLDOWN SYSTEM

REACTOR SAFETY and DIAGNOSTIC SYSTEM FUNCTIONS

1. Reactor Control System Malfunction Protection
2. Correction for Degradation of Temperature Feedback Signal
3. Diagnose Malfunctions and Report on Remaining Controllability
4. Monitor and Report Drum Misalignment
5. Report Reliability Status

NRX REACTOR SAFETY SYSTEM

REACTOR SAFETY & DIAGNOSTIC SYSTEM

REACTOR CONTROL SYSTEM MALFUNCTION PROTECTION

MALFUNCTION RECOVERY MODE

REDUNDANCY MODEL

FLIGHT DIAGNOSTIC AND CONTROL INSTRUMENTATION

I. INTRODUCTION

(U) The flight diagnostic and control instrumentation requirements are specified in ECC Spec 677565. This specification includes all reactor instruments, both diagnostic and control, required to assure meeting the performance requirements of the NSS CEI specification. This first viewgraph is a pictorial schematic of the instrumentation covered by the ECC specification. As can be seen, the ECC Spec covers exit gas thermocouples, high temperature core material thermocouples, absolute and differential pressure transducers, displacement transducers, both linear and angular for drum position measurement, neutronics detectors, low and intermediate temperature thermocouples and RTTS, accelerometers and strain gages. The interface of the instrumentation is at the signal conditioning of the EPIC except for certain special signal conditioners such as that associated with the neutronics and variable reluctance or variable transformer transducers.

(U) We have defined control instrumentation as that instrumentation whose primary end use is to supply a signal via appropriate signal conditioning to an automatic control device such as described by Mr. Norman. Diagnostic instrumentation is that instrumentation which is used as a display in the crews compartment and is telemetered back to earth. The diagnostic instrumentation satisfies the PRD requirements for instrumentation "To detect the approach of a failure or an event which could injure the crew or damage the spacecraft" and "Instrumentation adequate to detect deteriorating situations or incipient failures". Of course, much of the instrumentation performs a dual purpose of control and diagnostic functions as shown on the viewgraph.

(U) The apportioned reliability goal for the flight diagnostic and control instrumentation system is .99995. That is, the probability of a failure which could affect the primary mission is 5 out of 100,000. We believe we can meet this goal by utilizing the best materials we can find, analyzing designs for deficiencies and redesigning as necessary. A reliability assessment will be made for each transducer and then used in the statistical equations to determine the quantity of redundant instruments required. Dependent on the basic reliability of each instrument, it is believed the number of redundant channels will be from 3 to 10. Very close

coordination with the controls group will be maintained to take whatever advantage is possible of the computer supervised system they have proposed.

(U) This next viewgraph indicates for each type of instrument included in the ECC specification the NRX application acceptance level and the limiting ECC specifications requirement. As can be seen from the viewgraph, low temperature thermocouples and RTTS and medium temperature thermocouples are already at the level required by the ECC Spec. Only minor modifications are anticipated to improve reliability. Formal qualification tests will be performed, however.

(U) (Read from viewgraph the remaining types of instruments and requirements). These instruments will be covered in some detail in the remainder of this presentation.

High Temperature Core Material Thermocouples

(U) This viewgraph shows the requirements, the problems and the development approach proposed to solve the problems. (Read the requirements.) Past development progress has brought us very close to achievement of capability to meet the requirements. Past development testing has been successful to 4600°R and above but two problems remain as shown. Tungsten rhenium alloy sheaths have a ternary eutectic with carbon at about 4700°R which is very close to the maximum predicted value of 4600°R. However, extruded thoriated tungsten is very expensive - about \$30 an inch. Our design approach is to work with vendors to reduce the cost of the thoriated tungsten sheath and as a backup investigate CVD tungsten 25% Re. The second problem that remains is wire breakage during temperature cycling. This has occurred on the second or third temp cycling and is attributed to imperfections in the thermoelement wire which gets brittle as it is heated and then breaks at the weak point. The more the wire is cycled and the longer the hot zone, the more probable wire breakage becomes. Since the application of high temperature thermocouples extends beyond station 20, wire breakage is a severe problem. The development approach is to develop wire with improved grain structure without voids or cracks. This development will be initiated at the starting billet from which the wire is to be drawn and followed throughout all the processes to the end product.

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Exit Gas Thermocouples

- (U) The exit gas thermocouples are required for the safety and diagnostic control system and for diagnostic data on performance. This viewgraph shows the requirements (Read requirements from viewgraph). On NRX-A6 the exit gas thermocouples performed very well at temperatures up to 4600°R for one hour. However, for the NERVA application, the NRX design is obsolete since it relied on flow through the hollow tie rod to cool the sheath transition braze. Also a different hot zone sheath material is required to achieve operation at 4950°R . To provide a strong, durable sheath capable of withstanding the high temperature, we plan to use grain growth inhibited tungsten, probably thoriated, to improve the metallurgical structure.
- (CRD) The second problem is one of the mounting hardware and accuracy. The original concept was to extend the thermocouple through the support stem end cap axially into the exit gas plenum. Heat transfer calculations, however, indicate that such a design would cause the thermocouple to read 200 to 300°R low. By mounting the thermocouple element at right angles to the exit gas flow stream the heat transfer coefficient is improved by a factor of ten and error due to heat transfer of gas to thermocouple becomes negligible. The design problems, however, become significant. We have looked at a number of designs and are presently fabricating two development models. One model will make a 90° bend in the stainless steel extension sheath inside the support stem end cap with an electron beam welded transition to the hot zone tungsten sheath which will extend through the side of the end cap into the gas stream. The major problem with this design is that the limited space requires a bend of sheath, wire and insulation of about a $3/16$ -inch radius which may prove to be impractical from the reliability viewpoint. The other design utilizes a transition inside the end cap extending axially through the end cap with a 90° bend in the tungsten sheath outside the support system to obtain the desired cross flow. We have successfully bent several test pieces of tungsten and are now endeavoring to assemble thermocouples, using these test pieces with specially shaped insulators.

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Displacement Transducers

- (U) Displacement transducers are required for diagnostic data on the displacement of structural components such as between the core and the core support plate, the core and the pressure vessel, and they may be used to measure core lateral motion by replacing the present strain gage instrumented push rods with LVDT's.
- (U) The LVDT's now available, of a size that can fit into necessary reactor locations do not have sufficient displacement range when mounted in the available space which is limited to about 2 inches overall. Presently available transducers that fit into a 2 inch space usually will not measure over ± 0.125 inch within any degree of accuracy. Extending the range beyond this present limitation results in poor linearity. In addition, if larger size transducers are used they make a bigger target for gamma heating which results in overheating of internal components. In addition to having limited range presently available units also exhibit gamma heating effects on internal components that degrade their accuracy.
- (U) Development units have been redesigned with high temperature coil materials and with high Curie magnetic materials so that high temperatures in the internal components will not degrade them. In addition, all voids in the development units have been back filled with metal oxide powder to give good thermal conducting paths to the cage which will be cooled by gas flow. Thermal analysis of the units presently in development indicates that in a 7 watt per gram radiation environment and cooled by 260 R hydrogen the hot spot will be 463 R (3°F). In addition, the range of these units has been extended by winding them with finer wires and by putting more turns at the ends of the coils to give better linearity. Development transducers made in this manner have exhibited a displacement range of $\pm .300$ inch with a linearity of approximately 1%. This unit is the same size as the present ± 0.125 inch displacement range unit.

Drum Position Indicator

- (U) This instrument is required by control to monitor the angular position of the individual drums in the ganged drum control system. An accuracy of ± 1 degree between drums is required. In addition, the monitoring instrumentation will be mounted in an as yet undetermined radiation

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environment that may be as high as 10 watts per gram and will probably not be less than 7 watts per gram. The problem with this measurement is that high accuracy in a high radiation field is required.

- (U) The primary development approach will be to utilize the 2% accuracy LVDT's with a cam on the control drum shaft that will convert angular motion to linear motion. The desired accuracy can be achieved by calibrating each transducer-cam-drum system individually as these LVDT's exhibit some linearity and hysteresis. However, by calibrating the system the errors due to these sources can be virtually eliminated. If the development with the LVDT does not prove feasible, it may be necessary to develop a radiation hardened potentiometer of the necessary accuracy.

Accelerometers

- (U) Accelerometers are required for diagnostic purposes to monitor vibration of structural components of the reactor and the reactor pressure vessel. A range of ± 10 g is required to fully cover the range of $\pm 6-4g$'s required by the CEI Spec. These units should be accurate to $\pm 5\%$ and should be suitable for operation in radiation environments having heating rates as high as 9 watts per gram. The accelerometer is a weak link in the instrumentation development program. There has been no development at all since September, 1965 when a radiation test was run at the Plum Brook reactor. Work prior to this was never carried out to any conclusion that permits us to say that we really know the problems associated with radiation resistant accelerometers.

- (U) Presently available accelerometers which were used in the technology program function only at startup and shutdown. They exhibit a sensitivity shift of approximately 30% at a gamma heating rate of 1 watt per gram. In addition, they saturate under full reactor power conditions. However, since they recover and give shutdown data it is believed that the degradation of output is due to neutron effect on the magnetic materials.

- (U) To produce an accelerometer suitable for telemetry to a pilots display in a space vehicle it will be necessary to analyze these units fully to determine the cause or causes

of the malfunction. Then, attempts will be made to redesign this item to evolve units that operate accurately throughout a full reactor run.

Pressure Transducers

- (U) Pressure transducers are required for diagnostic measurements of absolute and differential fluid pressures in various reactor plena. Absolute transducers must operate over a range of 0 to 950 PSIA. Differential pressure transducers must operate over a range of 0 to 350 PSID. An accuracy of ± 2 percent of full range is required. These units should be internally mounted and preferably at the point of measurement to improve accuracy and to eliminate lines to increase reliability and to eliminate line response problems. By mounting these units internally, it will be possible to eliminate hydrogen penetrations through the pressure vessel. If a cable would break, only the measurement would be lost as the ceramic insulated cables are an effective pressure seal, however, if a hydrogen line breaks there is a direct leak from the pressure vessel.
- (U) Presently available pressure transducers are susceptible to radiation degradation and must be mounted in a shielded environment inside the pressure vessel, with lines to the point of measurement or must be mounted outside the pressure vessel.
- (U) Pressure transducers have been redesigned with high temperature coil material and with the case removed to permit reactor cooling gas to cool all components subject to gamma heating. Candidate transducers were installed in NRX-A6 and performed better than closed case models of the same transducer. However, they read lower than monitoring transducers mounted outside the pressure vessel. This lower reading is attributed to neutron effects on the diaphragm materials. It is intended to do further work with these units to redesign them with different diaphragms in order to eliminate these neutron effects. Accompanying these open case variable reluctance units in NRX-A6 were two thin film strain gage type pressure transducers that were being used by WANL for the first time. These units appeared to perform very well in NRX-A6, however, the radiation environments in which they were mounted is not too well defined so that the tests must be considered inconclusive. Further work will also be done with these strain gage type pressure transducers to determine if they will be more suitable for

our application than the variable reluctance type.

Strain Transducers

- (U) Strain gages are required for diagnostic measurements of the strain and load in critical reactor components such as bolt stand-offs, core lateral motion gages, the reactor support system, the support plate and the Beryllium reflectors. The range required is 0 to 5000 microinches per inch with an accuracy of ± 200 microinches per inch for static measurements and ± 50 microinches per inch for dynamic measurements. These gages will experience temperatures over the range of 37°R to 1060°R and will be mounted in radiation environments having gamma heating rates as high as 10 watts per gram.
- (U) Strain gages probably require more development work than any of the other components to evolve suitable systems that will monitor strains inside the reactor vessel of a flight vehicle. The presently available weldable strain gages are too large for support system mounting. In addition, techniques must be worked out to mount strain gages on the support system. The weldable strain gages exhibit a permanent zero shift under irradiation which is attributed to neutron effects. If the use of push rods with strain gages to monitor cold lateral displacement is continued, it will be necessary to eliminate the radiation effects from these gages. If weldable strain gages are to be applied to the Beryllium reflector it will be necessary to evolve methods of gage attachment to the Beryllium reflector that will impart accurate strain measurements to the gage and will not in any way damage or degrade the reflector material.

- (U) Bondable strain gages do not exhibit the zero shift problem, however, these gages are not temperature compensated and some means of adding additional instrumentation such as a thermocouple on the gages would be required to compensate these gages. Even if the bondable gage can be temperature compensated, the methods of attaching leads to these gages with any degree of reliability appears to be almost insurmountable.
- (U) The evolution of a proper strain gage for reactor installation seems to require that we redesign the presently available welded gages to eliminate zero shifts. Analysis of this phenomena to the beginning of CY 68 when the program was curtailed indicated that the strain wires used were definitely subject to radiation damage. The alloy being used by the gage manufacturer is a complex alloy that has been evolved to show minimal resistance change over the range of 0 to 90°F, since most industrial gages are applied over this temperature range. However, the complex alloy does not stand up well under radiation. The use of elemental strain wires, or the use of more simplified alloys, will be explored to determine if the radiation effects can be eliminated. At any rate, it will probably be necessary to use the best available weldable strain gages than can be evolved as it does not appear practical to use bondable gages in the reactor.

H. NEUTRONICS

- (U) Nuclear instrumentation is required for criticality checks, period information during startups and period and power information for the safety and diagnostic system. The requirements are shown on this viewgraph. (Read requirements from viewgraph.) As indicated, to obtain the accuracy required over the entire range, several detectors will be required. Their ranges will overlap to insure a continuous signal. Gamma compensation is another problem, especially during restart. We plan to investigate pulse counting techniques as well as current measuring techniques. To obtain gamma compensation with the miniature in vessel detectors, separate gamma detectors will probably be required and the compensation performed in the electronics. Pulse counting systems will require preamps that must be capable of withstanding the radiation level at their location which will, of necessity, be close to the pressure vessel.

PRESENT STATUS OF DIAGNOSTIC & CONTROL INSTR.

<u>Type</u>	<u>Use</u>	<u>Present Application</u> <u>Acceptance Level</u>	<u>ECC Spec. Req.</u>	<u>Comment</u>
Low Temp. TC's & RTTS	Gas Temp.	One Percent to 3000 R	One Percent to 3000 R	
Medium Temp. TC's.	Core Mat'l.	$\pm 50^{\circ}$ R up to 4200° R	$\pm 50^{\circ}$ R up to 4200° R	
High Temp. Core Mat'l. TC's.	Core Mat'l. Temp.	4200° R	Max of 4600° R + 50 - 150 R	
Exit Gas TC's.	Cluster Exit Gas Temp.	4285° R	4950° R + 50 - 150° R	Existing TC's Ran For 1 hr. up to 4600° R in NRX-A6.
Displacement Transducers	Core and Support Plate; Core and Pressure Vessel.	$\pm 0.125"$ Displacement, 1 Watt/Gram.	$\pm 0.300"$ Displacement, 10 Watts/Gram	
Drum Position Indicator	Individual Drum Position	New Measurement	Not Defined	
Strain Gages	Core Structural Strain	$\pm 500 \mu$ in/in Plus Zero Shift.	200 μ in/in Static 50 μ in/in Dynamic.	Present Units Drift Under Irradiation. Size Too Large For NERVA Application.
Accelerometers	Core & Support Structure Vibration		10g's Continuous Operation	Present Units Do Not Operate at High Reactor Power.
Pressure Trans.	Meas. ABS & Diff. Fluid Press. in Various Plena.		2% of Range Internal MTG.	
Neutronics	Measure Reactor Power	$\pm 10\%$ (External MTG)	Internal MTG. $\pm 10\%$	

HIGH TEMP. CORE MAT'L. TC'S

Requirements

- 1) Measure Core Mat'l. Temp. up to 4600° R.
- 2) Accuracy of + 50°, - 150° R at Design Temp.
- 3) 75 Min. Operation, Including 10 Starts.
- 4) Response Time of 0.1 Sec.

Problems

- 1) Expensive Sheath Material
(Extruded Thoriated Tungsten)
- 2) Wire Breakage During Temp. Cycling

Development Approach

Improve Metallurgical Condition of Extruded Tungsten & CVD W 25% Re Alloy.

Alternate - Investigate Use of CVD Thoriated Tungsten.

Wire Development Program to Improve Grain Structure and Eliminate Defects and Cracks.

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EXIT GAS THERMOCOUPLES

Requirements

- 1) 4550° R Design
- 2) 4950° R Max
- 3) Accuracy of $\pm 50^\circ$ at Design Temp.
- 4) 75 Min. Operation, Including 10 Starts.
- 5) Response Time - 0.1 Sec. in Range of 1000 R to 4550 R.

Problems

- 1) Strength and Durability of Sheath at Extremely High Temp.
- 2) Need to Project Junction Into Gas Stream at Right Angles.

Development Approach

Development of Grain Growth Inhibited Tungsten

- (a) Develop Design With Bend Inside of Mounting Hardware.
- (b) Develop Design With Bend Outside of Mounting Hardware.

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DISPLACEMENT TRANSDUCERS

Requirements

- 1) Range $\pm .300''$
- 2) Accuracy $\pm 2\%$ of Range.
- 3) 75 Min. Full Power, Including 10 Starts.
- 4) Radiation Environment up to 10 W/Gram.
- 5) Response Time TBD.

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Problems

- 1) Maintain Small Size While Increasing Range.
- 2) Insufficient Resistance to Radiation Environment.

Development Approach

Redesign Development Unit to be More Linear so Full Available Travel Can be Utilized.

Redesign Development Unit With Inorganic Coil Materials and High Curie Point Magnetic Materials.
Fill All Voids With Metal Oxide Powder.

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DRUM POSITION INDICATOR

Requirements

- 1) Measure Angular Position of Each Drum Over 180 Degrees.
- 2) Accuracy ± 1.0 Degree.
- 3) 75 Min. Full Power, Including 10 Starts.
- 4) Radiation Environment Up to 10 W/Gram.
- 5) Response Time TBD.

Problems

High Accuracy in Strong Radiation Environment

Development Approach

- (a) Utilize 2% Accuracy LVDT With Cam and Calibrate Each Transducer-Cam-Drum System Individually.
- (b) Investigate Radiation Resistant Potentiometer.

ACCELEROMETERS

Requirements

- 1) Range $\pm 10g$.
- 2) Accuracy $\pm 5\%$.
- 3) Radiation Environment - 9 Watts/Gram.
- 4) 75 Min. at Full Power With 10 Starts.

Problems

- 1) Function Only at Startup and Shutdown.
(Tentatively Attributed to Radiation Effects.)

Development Approach

- (a) Analyze to Determine Causes of Malfunction.
- (b) Redesign Units to Eliminate Causes of Malfunction.

PRESSURE TRANSDUCERS

Requirements

- 1) Range 0 to 950 PSIA
0 to 350 PSID.
- 2) Accuracy $\pm 2\%$ of Full Range.
- 3) Response Time Including Associated Impulse
Tubing TBD.
- 4) 75 Min. Full Power With 10 Starts.
- 5) Internally Mounted in Radiation Environment TBD.

Problems

- 1) Present Units are Susceptible to Radiation Effects.

Development Approach

- (a) Continue Development of "Open Case" Variable Reluctance Type to Minimize Gamma Heating of VR Units.
- (b) Development Testing of VR Units to Determine Effects Of Neutron Dose.
- (c) Continue Development Work With Thin Film Strain Gage Type.

STRAIN MEASUREMENTS

Requirements

- 1) Range 0-5000 Microinches/inch.
- 2) Accuracy $\begin{matrix} + \\ - \end{matrix} 200 \mu \text{ in/in}$ For Static
 $\begin{matrix} + \\ - \end{matrix} 50 \mu \text{ in/in}$ For Dynamic.
- 3) Temp. Range 37° R to 1060° R .
- 4) Radiation Environment - 10 Watts/Gram.
- 5) 75 Min. Full Power.

Problems

- 1) Present Weldable Strain Gages Too Large For Support System.
- 2) Bondable Gages Are Not Temperature Compensated and Lead Attachment is Not Practical.
- 3) Weldable Gages Exhibit Permanent Zero Shift Under Irradiation.

Development Approach

- (a) Analyze to Determine Causes of Malfunction.
- (b) Redesign Units to Eliminate Causes of Malfunction.

NEUTRONICS

Requirements

- 1) Monitor Neutron Flux From Source Level to 1.5 Full Power.
- 2) Accuracy 10% of Point.
- 3) Internally Mounted Detectors.

Problems

- 1) No One Detector Available for Entire Range.
- 2) Gamma Compensation During Restart.
- 3) Internal Mounting.

Development Approach

Use Multiple Overlapping Range Detectors.

Investigate Use of Pulse Counting System. Radiation Hardened Preamp Required if Pulse System is Used.

Develop Miniature Detector.

Flight Diagnostic and Control Instrument System

Formal Qualification Test Program

Formal Qualification

Primary Performance Characteristics .

General Design Features.

Selection of Specifications and Standards,
Materials, Parts and Processes.

Standard and Commercial Parts Workmanship.

Identification and Marking.

Reliability

Method

Inspection - Each Feature and/or Requirement Shall be Verified by Visual Inspection of Hardware, Procedures, Specifications, Operating Records, and Drawings.

Tests - Each Transducer Design Shall be Tested in Conformance With Applicable WANL Qualification Spec referred to in Section 2 of EC-677565. These Specs Contain Full Details on Both Non-nuclear and Nuclear Testing.

Tests and Analysis - Design Reviews, Readiness Reviews, Inspections, Failure Mode Analysis, and Reliability and Test Evaluations.

GANGED DRUM ACTUATOR SYSTEM

- (U) The subject of this presentation is the Control Drum Actuator System. This system CEI is subordinate to the Nuclear Subsystem CEI in the configuration management specification tree.
- (U) The first figure identifies the system components and indicates their interfacing with the pressure vessel, the drum ganging mechanism, and the reactor control and power distribution systems. Multiple actuators and their mounting pedestals in conjunction with a single controller comprise the elements of a position servo moderated by a velocity limit override.
- (U) This presentation will include discussion of the proposed and alternate design solutions for the system constituent elements, the developmental and qualification test program, and the system performance requirements which are displayed on the next figure.
- (U) These primary functional characteristics are those necessitated by inference from the Nuclear Subsystem CEI as formulated by the WANL departments sharing responsibility for its implementation. The NSS requirements principally influencing the CDAS Spec are those relating to startup and shutdown rates, steady-state temperature limits, endurance, reliability and safety.

<u>Positioning:</u>	Required to position ganged array without introducing imbalance in torque distribution.
<u>Working Range:</u>	Increased from 150° to 165° for more effective utilization of drums.
<u>Stops:</u>	Reduced from 15° to 7.5° to permit increased working range. This reduction allowed by lowered velocity limits and elimination of open loop scram mode.
<u>Accuracy:</u>	Allowable position deviation reduced from $\pm 2^\circ$ to $\pm 1^\circ$ to maintain better core temperature distribution towards objective of maximized endurance.

<u>Resolution:</u>	Same as XE.
<u>Velocity Limits:</u>	Reduced from $100^{\circ}/\text{sec}$ to $10^{\circ}/\text{sec}$ for added safety, increased position loop stability margin.
<u>Dynamic Performance:</u>	While not inconsistent with XE capacity, the revised spec amplitude more nearly represents reactor control loop requirements, rather than the secondary requirements of position loop stability.
<u>Reliability:</u>	Operation of the actuators in ganged array, consolidation of control elements into a redundant configuration, and extensive simplification of the basic actuator will insure attainment of reliability goal.

(U) Re-examination was made of actuator mechanisms offering possible applicability as a design solution. An earlier presentation of the alternatives resulted in the acceptance of the basic design incorporated in the XE pneumatic actuator, manufactured by G. E., as being most suitable for application to the NERVA drum control system. This decision was made since none of the alternative candidate actuators evidenced obvious promise of superior performance or reliability. No incentive therefore existed to abandon the XE pneumatic actuator and submit to the inevitable schedule delay and increased development cost attendant with selection of an actuator relatively unknown in character deficiencies.

(U) The next figure depicts the XE actuator configuration. It is intended that this basic actuator be revised sufficiently to satisfy the requirements of the NERVA Actuator System.

(U) This actuator employs two opposed pneumatic powered pistons driving a rack and complementary pinion drive shaft. Pneumatic pressures in the cylinders are controlled by a servo valve which perform the electro-pneumatic analog conversion. Loop feedback information is supplied by a redundant array of potentiometers coupled to the drive shaft. Travel limit constraints are effected by a helical soft stop spring mounted internally in the tubular drive

shaft. Further constraints on drive shaft position are imposed by manual and electro-pneumatic locks and by another helical spring whose function is to control the rebound resulting from an open loop, hi-velocity scram impact with the soft stop. Coupling to the individual drum drive shaft is achieved through a crown tooth spline which allows transverse and longitudinal misalignment of the drum and actuator. The scram springs employed in the XE reactors eliminate backlash from this spline.

(U) The next figure shows a simplified schematic of the XE system configuration. As is required of NERVA system, the elements comprise a position loop. The rate loop acts only on the feedback signal and provides lead stabilization for low signal amplitudes. For larger signal amplitudes, this loop overrides the position loop and imposes a limitation on the attainable drum angular velocity. Redundancy exists only in the feedback instrumentation and in wiring.

(U) Note particularly the pneumatic integration incorporated in the actuator to provide the high static gain necessary to satisfy position resolution and accuracy requirements. This element will be referred to in subsequent discussions.

(U) A schematic similar to this is shown in the following figure in which the proposed NERVA system configuration is represented. It is not intended that this schematic accurately define the multiplicity of redundancy paths. A comprehensive study is required to finally establish the required redundancy and sequence of the constituent elements to assure compliance with the reliability goal. Most assuredly, the signal conditioning sections will ultimately be more numerous than shown here, while on the other hand, an eighteen (18) fold redundancy in the feedback instrumentation seems superfluous for a single parameter measurement. It is intended that all system components share a common excitation voltage rating so that redundancy may be extended to power supplies without undue penalty. This system configuration will undergo examination and whatever revision deemed necessary to insure that any credible combination of element failures will not compromise the ability to satisfy the primary functional requirements consistent with the reliability goal.

- (U) The signal conditioning sections used in the controller are essentially similar to those employed on XE, with loop compensation details refined as necessary. Mid-value selection of the signal conditioning sections permits consolidation of the control function into the single selected section; thus, applying identical inputs to the power amplifiers controlling individual actuators.
- (U) Again note particularly that the integration function formerly assigned to the actuator is now incorporated into the mixer stage upstream of the signal divergence into the separate power amplifiers and actuators. A subsequent discussion of the servo valve should clarify how this arrangement will permit ganging of the actuators without encountering the problem of fighting among the actuators.
- (U) The next figure shows the XE actuator schematic. The cylinder pressures are controlled by the ratio of the pneumatic impedances offered by the fixed supply orifice and the variable valve nozzle. Since these nozzles reside at opposing ends of the torquemotor armature, the cylinder pressures respond oppositely to motion of the armature, with the consequence that the resultant torques applied to the drive shaft are additive. The pressures and nozzle areas are of such magnitude that nozzle forces often exceed the unaided capacity of the torquemotor to assume locations required by the control loop. For this reason, bellows are employed that aid the armature. A porous orifice restricts flow into the bellows volume to effect the integration referred to earlier. The bellows area is sized very slightly larger than the nozzle area, which results in an extremely high static current to pressure gain.
- (U) The next figure compares the XE servo valve design with the redesign intended for NERVA application. The cross-section is routed so that the porting associated with one cylinder is unfolded. Porting for the other cylinder is a mirror image. In the XE valve, the supply orifice plate is sandwiched between two apex seals. Downstream of this orifice is the valve nozzle with a flapper screw equipped with a spherical pivot to provide adjustment for nozzle shutoff. Its purpose is to assure realization of maximum stall torque capability to be applied

in the event of a stuck drum. The long horizontal port communicates to the cylinder porting and to the bellows porous orifice. Downstream of the porous orifice, in addition to the bellows, there is porting that expands into the actuator housing to provide a volume that acts in conjunction with the orifice as a component of the bellows lag network.

(U) The bellows and the lag network are deleted from the NERVA valve. The integration function is much more reliably achieved by the simple addition of capacitors to the signal conditioning section of the controller. As the two seals associated with each bellows are by far the most critical in the entire actuator with regard to the consequences of slight leakage, a contribution to the actuator reliability is made by their absence. The bellows too, being a relatively fragile device, is not universally regarded with favor. Its elimination, however, poses the problem of nozzle force loading on the torquemotor. A redesign of the nozzle and flapper screw to a bi-directional flow arrangement offers the solution. A nozzle core piece reduces the nozzle to an annular area only 30 percent the size of the XE nozzle area. As shown in the nozzle cross-section view, the core is supported at three points contacting the cylindrical nozzle shell below the circular nozzle mouth. This does not constitute a reduction of the flow control area. This control area is proportional to the nozzle lip circumference. Since in this nozzle both the inner and outer lip is utilized, flow control area is actually increased by 50 percent. Flow from the cylinder porting is routed past the three flats on the core plug and then divided radially inward and outward through the control area. Inward flow is exhausted from the hollow portion of the flapper screw through the six port holes on the faces of the hex wrench seat. The 50 percent increase in flow control area permits an increase in the drum inertia load assigned to each actuator without encountering flow saturation degradation of the position loop stability margin.

(U) Since the ganged configuration, the problem of a stuck drum does not demand attainment of the full stall torque potential from each actuator, the need for adjustable nozzle seating is not felt to be required. However, if nozzle and flapper screw alignment varies too severely, the alternate flapper screw geometry provides seating adjustment. The adjustment is effected

by a two piece construction employing a spring loaded spherical collet. The flapper screw application is less demanding than for the XE screw in that a pressure seal is not required of the spherical pivot surface. It is felt, however, that the rigid flapper screw offers greater reliability and that adequate nozzle alignment can be assured by simplifying the valve structure. Whereas alignment of the XE valve components was achieved by way of a manifold bristling with dowel pins, the redesigned valve easily assures alignment by matching the flapper screw holes in the torque motor armature with nozzle locating holes integrated into the torque motor base. The torque motor armature support flexure spring will be changed to provide a stiffer gradient. In addition to incorporation of the bellows spring gradient into this spring, the gradient will be further increased to aid in ganging and to gain added tolerance to the larger vibration amplitudes anticipated on the NERVA application. The combined effects of the smaller nozzle area, a shorter cylinder porting length, and the increased spring gradient add significantly to the servo valve hi-frequency stability margin, which for a considerable time constituted a problem of formidable dimension on the XE valve. This added stability will further insure that any vibration induced in the torque motor armature will not be pneumatically amplified.

(U) Other changes planned on this valve include conversion of the coil winding a voltage common to the control system. Also, the flapper screw mounting thread has been enlarged to avoid previously encountered problems with the 4-40 XE screws and their small allen socket. Manifold-housing interface seals cavities transferred to the housing to facilitate repair of seal surface damage.

(U) The next figure shows an empirical performance data comparison of XE and prototype NERVA servo valves; the NERVA data is shown in solid line. This data was taken using helium gas at ambient temperature and was originally plotted directly by an X-Y, Y^1 recorder, which explains why no data points are visible.

(U) Examination of the static plot of differential cylinder pressure versus current should make clear, finally, why it is impossible to gang the XE actuators. Since the XE static gain is nearly infinite, and individual actuator position control is prohibited by the ganging mechanism;

an attempt at ganging would result in actuators divided into two equal groups exhibiting quiescent cylinder pressures at opposing stall torque values with a dynamic capability virtually non-existent.

(U) Examination of the data taken on the prototype NERVA valve, however, lends credence to the view that the NERVA actuators can indeed be ganged. This valve displays a finite and quite linear slope. While it is unlikely that tolerance control of the individual valve parameters will result in precise matching of the static gain for each of the valves, the voltage to pressure gain of the combined power amplifier and valve can be very easily adjusted to achieve precise matching of the static gains. Likewise, besides adjusting the valves to obtain the null pressure intercept, a power amplifier DC offset adjustment can provide trim matching.

(U) The dynamic performance data shows that unlike the XE valve, the static gain value of psi/ma extends nearly through the active frequency range of the actuator. The NERVA valve does not of course exhibit the low frequency lag and lead associated with the bellows. This insures that matching of the static voltage to pressure gain for all the actuators will also result in matching of the dynamic gain throughout the frequencies of interest. Thus all actuators can be reasonably expected to have very nearly equal quiescent and dynamic cylinder pressures.

(U) The prototype valve was tested at 140°R cryogenic temperatures on helium, and the rolloff in gain occurred at slightly lower frequencies as predicted by the analytical model and as experienced on the XE valve. As no evidence of valve instability was apparent, this test provided confirmation of the increased stability margin. The test was conducted without the pneumatic resistance elements normally used in the cylinder porting to suppress the oscillation frequently experienced on the XE valve when used with helium at these temperatures. The 9 lb difference in gain at frequencies beyond the influence of the bellows is a measure of the stability margin effected by the reduction in nozzle area. This increase in gain results from the reduction in nozzle feedback force.

(U) The next figure compares the XE actuator with one incorporating proposed NERVA changes.

- (U) The XE actuator employs a manual safety lock and a dual purpose electro-pneumatic lock. Its prime purpose is to provide remotely controlled constraint on the drums to a shutdown position. It further functions to moderate drum rebound following a hi-velocity scram impact with the soft stop.
- (U) These locking mechanisms do not adequately satisfy the requirements of the NERVA system. It is therefore intended that an engineering evaluation study will make a comprehensive examination of the system needs and devise alternative mechanisms that do satisfy the needs of flight safety and reliability.
- (U) The XE lock is assigned the task of pulling or inserting a pin to inhibit drive shaft motion. Examination of the illustration will reveal that a disproportionately complex array of components is devoted to the execution of this relatively simple function. The lock pin is actuated by a pneumatic piston and cylinder spring loaded to interfere with a cam which is splined to the drive shaft. The cylinder pressure is controlled by a two way solenoid valve. Two miniature switches actuated by adjustable cams on the lock pin provide position feedback information. Overriding control on the pneumatic lock pin is exercised by a manual pin which pierces the pressure shell by way of a bellows seal to communicate with a conventional tumbler-key lock. A large helical spring inside the tubular drive shaft acts in conjunction with the pneumatic lock to suppress scram rebound. While the problems encountered in the development of this lock mechanism have been resolved, its complexity suggests that it may be less reliable than relatively simple alternatives.
- (U) Since the NERVA system does not employ a high-velocity open loop scram mode, the rebound control function is not a requirement. Realistic manufacturing tolerances preclude accurate registry of the lock pins and cams between the various actuators. This poses the problem of possible inadvertent damage to the shear pins coupling the actuators to the drum bank in the event the actuators experience an out command without first extracting the lock pins. In this eventuality, the drum bank would move out until encountering the lock pin of only one actuator. The remaining actuators would then shear or partially shear that actuator

out of the system until the second pin was encountered. It is conceivable that the actuators would fall domino fashion until shear pin and actuator torques reached equilibrium.

- (U) Another concern is that the XE locking mechanism does not satisfy the need to hold the drums stationary in powered positions, as required by the malfunction recovery mode concept referred to earlier in the Reactor Control System presentation.
- (U) It is likely that the alternative locking system ultimately adopted will incorporate a control lock on the drive gas solenoid valve. This would be interlocked with the actuator system demand to prevent opening of this valve if an out demand existed.
- (U) The evaluation study will examine vibration amplitudes applied to the drum bank to determine the necessity for a supplementary device for maintaining drum position. If it is established that it is credible that torsional vibrations may exist with sufficient amplitude to overcome system static friction, then the need for additional mechanism will be confirmed.
- (U) An electromagnetically actuated friction or toothed brake, applying torque to the drum bank would satisfy the requirements of both flight safety and the malfunction recovery mode. It is believed that such a device would not represent a difficult development task and would evidence simplicity and reliability significantly superior to the XE lock mechanism.
- (U) A very simple alternative device that would fulfill any demonstrated need for suppression of random motion of the drum bank by induced vibration consists of a spiral spring. This spring could be easily incorporated into each actuator. The spring need not have a high torque value, but only sufficient to supply an inward bias if the system static friction is broken by torsional vibration.
- (U) Elimination of the multiple locks from the actuators in combination with the reduced envelope required to enclose the potentiometers and servo valve, would result in a weight saving probably exceeding four pounds per actuator. This change would also permit a reduction in the required electrical connections to half those needed in the XE actuator.

(U) Other contemplated changes include redesign of the actuator drive shaft coupling to a tapered anti-backlash configuration, and elimination of the three headed interface guide pins. These pins are used to aid in mounting of the XE actuators and are not required for NERVA. An alternative polyimide wire insulation is being considered to replace the fiber-glass and shrinkable tubing currently used on the harness. Wherever possible, aluminum parts will be protected from corrosion by an anodize rather than alodine coating.

These proposed changes are itemized in the summary figure.

(U) It is intended that any changes to the main drive train, (cylinders, pistons, rack and pinion drive shaft) will be restricted to very minor detail refinement that might result from a review examination. This drive train has demonstrated a high degree of reliability since no failure to perform its function has been experienced during the thousands of hours of AG-20 prototype and XE actuator testing. There is confidence among those intimately familiar with the actuator testing history and analytical studies that implementation of a locking system redesign and the proposed servo valve redesign in combination with the greatly expanded redundancy realized by ganging will produce an actuator system displaying, throughout its constituent elements, a high reliability consistent with that of the drive train.

(U) A tentative outline of the developmental and qualification test program is shown in the last figure. Detailed listing of the required formal qualification testing may be found in the Control Drum Actuator System CEI Specification CP-677585. Initial development testing can be largely achieved with the aid of modified XE test fixtures. Fixtures permitting testing in a ganged configuration are currently being developed. An 18 drum rig will serve as a dual purpose test fixture for both the actuator and ganging systems.

CONTROL DRUM ACTUATOR SYSTEM DIAGRAM

PRIMARY PERFORMANCE CHARACTERISTICS OF THE CONTROL DRUM ACTUATOR SYSTEM

POSITIONING

The CDAS shall be capable of positioning a drum bank that displays the combined characteristics of the Ganged Drive System and the drum portion of the Reflector and Axial Support System (EC 677560 and EC 677559 respectively).

WORKING RANGE

The CDAS shall operate the drum bank free of snubbing restraints over an angular range of $165^{\circ} \pm 3^{\circ}$.

STOPS

Angular positions beyond the limits of the working range shall be opposed by a snubbing "soft stop" spring having zero preload and a gradient of 50 ± 5 in-lb/degree and through an angular travel not less than 7.5 degrees at either end of total travel.

ACCURACY

The CDAS shall maintain a static drum bank position accuracy of $\pm 1^{\circ}$ relative to demand throughout the working range.

RESOLUTION

The CDAS shall have a static resolution of 0.2 degrees maximum.

VELOCITY LIMITS

The CDAS shall be capable of rotating the drum bank at a controlled maximum angular velocity of 10 ± 3 degrees/second.

DYNAMIC PERFORMANCE

The CDAS shall exhibit a frequency response bandwidth of 1.0 Hz min. for a demand signal amplitude of 1.0 degree peak to peak. At frequencies less than or equal to 1.0 Hz the attenuation shall not exceed 3 db.

RELIABILITY

The apportioned reliability goal for the CDAS shall be a probability of .99989 that it will meet the primary performance requirements throughout its useful life.

XE CONTROL DRUM ACTUATOR SYSTEM
CONFIGURATION SCHEMATIC
(12 UNITS)

XE ACTUATOR SCHEMATIC

XE-1, XE-2 SERVOVALVE

PROPOSED SERVOVALVE FOR NERVA APPLICATION

XE & PROTOTYPE NERVA SERVOVALVE PERFORMANCE TEST DATA
CYLINDER DIFFERENTIAL PRESSURE vs TORQUEMOTOR CURRENT

$$\left(\frac{\Delta P}{\Delta I}\right)$$

XE ACTUATOR

PROPOSED NERVA ACTUATOR

SUMMARY OF PROPOSED CHANGES TO ACTUATOR SYSTEM

PRIMARY

1. Delete bellows and pneumatic lag network. Transfer integration function from actuator to controller to implement ganging.
2. Redesign servovalve nozzle to annular configuration.
3. Replace manual and electro-pneumatic locks with control lock on drive gas solenoid valve, supplemented if necessary by additional simple mechanism.

SECONDARY

1. Redesign driveshaft coupling to anti-backlash configuration.
2. Servovalve geometry modified to simplify machining, improve nozzle alignment, and to increase both stability margin and vibration tolerance.
3. Eliminate half of servovalve seals. Transfer servovalve and actuator interface seal cavities to provide improved seal surface protection.
4. Lower velocity limit.
5. Eliminate scram rebound spring.
6. Eliminate all headed interface guide pins.
7. Improve corrosion resistance.
8. Improve harness wire insulation.
9. Reduce electrical connections by half.
10. Reduce feedback potentiometer compliment by one third.
11. Convert feedback pot and torquemotor to a voltage excitation common to the control system to reduce power. supply requirements.
12. Reduce system size and weight.

CONTROL DRUM ACTUATOR SYSTEM

TEST PROGRAM

<u>COMPONENT DEVELOPMENT</u>	<u>PARAMETER OPTIMIZATION AND/OR EVALUATION</u>	<u>PRIME TEST FACILITIES</u>
Servovalve	Nozzle Geometry Spring Gradient Temperature Stability Performance	Servovalve Loadstand Pressure Loop Control Ambient and Cryogenic H _e
Coupling	Geometry Torque and Thrust Load Variation	Actuator Unit Loadstand Ambient and Cryogenic H _e and H ₂
Locking Mechanism	Configuration Optimization Performance Evaluation	Six-Gang Loadstand Ambient H _e and H ₂
Actuator and Controller Breadboard	Controller Configuration Servoloop Compensation Performance Environment	Actuator and Pedestal Vibration Stand Ambient and Cryogenic H _e Ganged 18 Drum Test Rig Ambient and Cryogenic H _e and H ₂

FORMAL QUALIFICATION

Actuator, Controller, Pedestal	Performance Useful Life Environmental Safety Corrosion Electromagnetic Interference
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ENGINEERING MECHANICS TEST RIG DESCRIPTION

OUTLINE

1. TEST AREAS COVERED BY ENGINEERING MECHANICS
2. MAJOR TEST RIG DESCRIPTION
3. RELATION TO ENGINEERING CRITICAL COMPONENT AND TESTS

ENGINEERING MECHANICS TEST RIG DESCRIPTION

TEST AREAS COVERED

THREE GENERAL TYPES OF TESTS:

1. DEVELOPMENT TEST - THOSE WHICH WILL PROVIDE THE EVALUATION AND ENGINEERING DATA NECESSARY TO DESIGN AND DEVELOP IMPROVED HARDWARE. LIMIT TESTING TO ESTABLISH DESIGN MARGIN AND SAFETY FACTORS WILL BE A MAJOR PART OF THESE TESTS.
2. PRE-QUALIFICATION TEST - THOSE WHICH WILL DEMONSTRATE THE CAPABILITY OF A COMPONENT TO FUNCTION AS DESIGNED UNDER SIMULATED CONDITIONS WHICH SUBJECT THE COMPONENT TO THE DESIGN PERFORMANCE LIMITS.
3. QUALIFICATION TEST - THOSE WHICH DEMONSTRATE THAT THE ITEM MEETS THE REQUIREMENTS OF FLIGHT BY TESTING FOR FLIGHT DURATIONS AND CYCLES UNDER SPECIFICATION EXTREME CONDITIONS.

ENGINEERING MECHANICS TEST RIG DESCRIPTION

TEST AREAS COVERED

ALL TESTS WILL REQUIRE SOME SIMULATION OF THE EXPECTED OPERATING ENVIRONMENT. IN THE TESTS TO BE CONDUCTED IN THE ENGINEERING MECHANICS LABORATORY THIS SIMULATION WILL INVOLVE THE APPLICATION OF STATIC AND/OR DYNAMIC LOADS TO MECHANICAL COMPONENTS AT STEADY STATE AND TRANSIENT TEMPERATURES RANGING FROM APPROXIMATELY 15°R TO 5000°R UNDER THE APPROPRIATE GASEOUS OR VACUUM CONDITIONS. THE TEST RIGS REQUIRED TO ACCOMPLISH THIS HAVE BEEN CATEGORIZED AS FOLLOWS:

- 1) STATIC LOAD TEST RIGS
SIMULATE THE STATIC LOADS CAUSED BY PRESSURE AND TEMPERATURE DIFFERENTIALS, "G" LOADS, PRE-LOADS AND THERMAL GRADIENTS. MAY INCLUDE THE CAPABILITY OF TESTING AT CRYOGENIC OR ELEVATED TEMPERATURES.
- 2) DYNAMIC LOAD TEST RIGS
SIMULATE THE VIBRATION ENVIRONMENT CAUSED BY TRANSPORTATION AND COMPONENT OR REACTOR OPERATION. MAY INCLUDE THE CAPABILITY OF TESTING AT CRYOGENIC OR ELEVATED TEMPERATURES.
- 3) COMBINED LOAD TEST RIGS
SIMULATE THE SIMULTANEOUS APPLICATION OF STATIC AND DYNAMIC LOADS.
- 4) TRANSIENT TEST RIGS
SIMULATE TRANSIENT THERMAL LOADS CAUSED BY REACTOR STARTUP AND SHUTDOWN. MAY INCLUDE CAPABILITY OF IMPOSING STEADY STATE AND/OR DYNAMIC LOADS.
- 5) ENVIRONMENTAL TEST RIGS
SIMULATE STORAGE, CORROSIVE AND SPACE CONDITIONS.

ENGINEERING MECHANICS TEST RIG DESCRIPTION

STATIC LOAD TEST RIGS

<u>NAME</u>	<u>COMPONENT TESTED</u>
1. HIGH TEMPERATURE CLUSTER BUNDLING FURNACE	CHESH, CAMH, FUEL ELEMENT
2. HIGH TEMPERATURE HORIZONTAL RIG	CORE PERIPHERY
3. AXIAL SUPPORT STATIC LOAD RIG	REFLECTOR AND AXIAL SUPPORT

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HIGH TEMPERATURE CLUSTER BUNDLING FURNACE

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V/G NO. 1 CLUSTER BUNDLING FURNACE

THE ABILITY OF ELEMENT HOT ENDS AND CLUSTER SUPPORT HARDWARE TO WITHSTAND THE COMBINED EFFECTS OF TEMPERATURE CYCLES, AXIAL PRESSURE DROP LOADS, CORE BUNDLING LOADS AND BENDING LOADS DUE TO DIFFERENTIAL EXPANSION WILL BE EVALUATED IN THE CLUSTER BUNDLING FURNACE.

THIS FURNACE HAS A 6" X 10" HOT WORKING ZONE WITH A 5000°R TEMPERATURE CAPABILITY. AXIAL LOADS UP TO 10,000 LBS CAN BE APPLIED THROUGH THE TOP OF THE FURNACE AND REACTED AGAINST THE BASE. 750 LB RADIAL LOADS, SIMULATING CORE BUNDLING, CAN ALSO BE SIMULTANEOUSLY APPLIED THROUGH EACH OF THE BUNDLING SHOES.

IN ADDITION TO THE SPECIAL GRAPHITE FIXTURING WHICH WILL BE REQUIRED FOR THE VARIOUS TESTS, MODIFICATIONS TO IMPROVE THE FURNACE COOLDOWN RATE AND THE EASE OF TOP LOADING WILL BE INCORPORATED FOR THE NERVA COMPONENT TEST PROGRAM.

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HIGH TEMPERATURE HORIZONTAL RIG

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V/G NO. 2 HORIZONTAL HIGH TEMPERATURE TEST RIG

CANDIDATE AND SELECTED DESIGN WRAPPER CONFIGURATIONS AND MATERIALS MUST BE TESTED TO DEMONSTRATE THEIR ABILITY TO CONFORM TO CORE GEOMETRY VARIATIONS DURING EXPANSION AND CONTRACTION, TO TRANSMIT THE CORE BUNDLING LOADS AND TO PROVIDE A BARRIER AGAINST HYDROGEN INFLOW. THE HORIZONTAL HIGH TEMPERATURE TEST RIG SHOWN IN THIS SLIDE WILL BE USED TO PROVIDE THIS TYPE OF INFORMATION.

IN THIS RIG IT IS POSSIBLE TO MOCKUP A PERIPHERAL SECTOR OF THE CORE AND TO IMPOSE BOTH THERMAL AND PRESSURE GRADIENTS ACROSS THE WRAPPER. THE OUTWARD EXPANSION OF THE ACTUAL CORE IS SIMULATED ON HEATUP, WHICH IN TURN SUBJECTS THE WRAPPER TO THE MECHANICAL STRAINS EXPECTED IN THE CORE.

THIS RIG IS PRESENTLY TEMPERATURE LIMITED AT 4000°R AND MODIFICATIONS WILL BE REQUIRED TO INCREASE THIS CAPABILITY TO 5000°R. IMPROVEMENTS MUST ALSO BE MADE IN THE HEATER ELECTRODE ASSEMBLY TO FACILITATE EASIER SETUP.

AXIAL SUPPORT STATIC LOAD RIG

V/G NO. 3 AXIAL SUPPORT STATIC LOAD RIG

THE REFLECTOR AND AXIAL SUPPORT SYSTEM MUST TRANSMIT ALL AXIAL CORE LOADS TO THE NOZZLE/PRESSURE VESSEL FLANGE AS WELL AS SUSTAINING THE RADIAL LOADS REQUIRED FOR SUPPORT OF THE CORE. THE CAPABILITY OF SELECTED DESIGN TO WITHSTAND THE STATIC AXIAL AND RADIAL LOADS WILL BE DEMONSTRATED IN A TEST RIG WHICH WILL BE A REDESIGN OF THE ONE SHOWN HERE.

THIS IS THE APPARATUS USED TO TEST THE AXIAL SUPPORT SYSTEM FOR THE EARLY NRX REACTORS. HYDRAULIC CYLINDERS WERE USED TO APPLY SIMULATED CORE PRESSURE DROP LOADS TO THE AXIAL SUPPORT COMPONENTS AT CRYOGENIC TEMPERATURES. SINCE THE LOADS WERE TRANSMITTED TO THE PRESSURE VESSEL AT THE FORWARD END CLOSURE, TESTS COULD BE CONDUCTED WITH THE SUPPORT PLATE DOWN TO SIMPLIFY THE PROBLEM OF COOLING.

THIS TEST RIG WILL REQUIRE A MAJOR DESIGN MODIFICATION TO PROVIDE PROPER COOLING OF ALL SUPPORT SYSTEM COMPONENTS, SINCE THE R1 DESIGN LOADS ARE TRANSMITTED THROUGH THE REFLECTOR TO THE NOZZLE EXTENSION AND PRESSURE VESSEL. A LOADING MECHANISM TO SIMULATE THE RADIAL LOADS FROM THE LATERAL SUPPORT SYSTEM DUE TO CORE EXPANSION AND MEANS FOR LATERAL CORE DISPLACEMENT MUST ALSO BE INCORPORATED.

ENGINEERING MECHANICS TEST RIG DESCRIPTION

DYNAMIC LOAD TEST RIGS

<u>NAME</u>	<u>COMPONENT TESTED</u>
1. PARTIAL CORE TEST RIG	LATERAL SUPPORT SYSTEM
2. VIBRATION CORE TEST RIG	ALL

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PARTIAL CORE TEST RIG

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V/G. No. 4 PARTIAL CORE TEST RIG

THE DYNAMIC AND WEAR CHARACTERISTICS OF THE LATERAL SUPPORT SYSTEM MUST BE ESTABLISHED AND THE ABILITY OF THE SELECTED DESIGN TO SUPPORT THE CORE UNDER VIBRATORY CONDITIONS VERIFIED. A PARTIAL LENGTH CORE LIKE THE ONE SHOWN WILL BE USED FOR THESE TESTS.

SHOWN IS THE NRX-A6 PARTIAL CORE WHICH ALLOWS FOUR ROWS OF THE LATERAL SUPPORT SYSTEM SEALS TO BE TESTED. ACTUAL LATERAL SUPPORT HARDWARE IS BUILT INTO A SIMULATED REFLECTOR AND THE CORE MASS SIMULATED BY A GRAPHITE CYLINDER. DYNAMIC FORCES IN THE 5 CPS TO 500 CPS RANGE AT "G" LEVELS UP TO 5 "G" ARE INPUT TO THE REFLECTOR.

THE SIMULATED REFLECTOR AND CORE WILL REQUIRE MODIFICATION TO INCORPORATE THE LATEST DESIGNS FOR FUTURE NERVA REACTOR TESTING. ALSO, A BETTER SIMULATION OF THE CORE END CONSTRAINTS WILL BE REQUIRED. THIS WILL BE IN THE FORM OF EITHER A FULL LENGTH CORE OR AN IMPROVEMENT OF THE 52" PIVOT USED FOR THE A-6 PARTIAL CORE.

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VIBRATION CORE TEST RIG

V/G NO. 5 VIBRATION REACTOR

AN UNFUELED REACTOR IS PLANNED AS A TEST RIG IN WHICH TO VERIFY THE DYNAMIC CHARACTERISTICS OF THE MAJOR CORE COMPONENTS. THIS TEST REACTOR WILL ALLOW SIMULATION OF THE INTERACTION OF ALL REACTOR COMPONENTS AND THE SIGNIFICANT ENGINE COMPONENTS ADJACENT TO THE REACTOR.

SHOWN IS THE ORIGINAL VIBRATION REACTOR USED TO CONDUCT NRX REACTOR DYNAMIC TESTS IN BOTH THE AXIAL AND LATERAL DIRECTIONS. THIS CORE USED UNFUELED ELEMENTS AND ACTUAL REACTOR HARDWARE INSIDE THE SIMULATED PRESSURE VESSEL.

A NEW CORE USING QUALIFICATION GRADE HARDWARE WILL BE BUILT FOR THE NERVA VIBRATION REACTOR AND SIMULATION OF THE PRESSURE VESSEL AND NOZZLE WILL BE INCLUDED. NEW INPUT AND HOLDING FIXTURING FOR BOTH HORIZONTAL AND VERTICAL TESTS MUST BE DESIGNED AND BUILT, AND RANDOM INPUT AND ANALYSIS EQUIPMENT MUST BE PROCURED. BUILDING MODIFICATION AND ADDITIONAL THRUSTER CAPABILITY MAY ALSO BE REQUIRED.

ENGINEERING MECHANICS TEST RIG DESCRIPTION

COMBINED LOAD TEST RIG

<u>NAME</u>	<u>COMPONENT TESTED</u>
1. COMBINED LOAD TEST RIG	SUPPORT STEM
2. 18 DRUM TEST RIG	GDDS, REFLECTOR & AXIAL SUPPORT

COMBINED LOAD TEST RIG

THE SUPPORT STEM MUST BE CAPABLE OF SUSTAINING STATIC AXIAL CORE LOADS, BENDING LOADS DUE TO CORE EXPANSION OR DISPLACEMENT AND DYNAMIC LOADS RESULTING FROM REACTOR LAUNCH AND OPERATION. THE ABILITY TO WITHSTAND THE SIMULTANEOUS APPLICATION OF ALL TYPES OF LOAD WILL BE DEMONSTRATED IN A TEST RIG WHICH EMBODIES FEATURES OF THE TEST RIGS SHOWN HERE.

ON THE LEFT IS A FIXTURE USED FOR EARLY NRX TESTING IN WHICH BUNDLING LOADS WERE APPLIED TO A 7 CLUSTER ASSEMBLY FOR VIBRATION TESTING. ON THE RIGHT IS A DEVICE USED TO SIMULATE CORE TRANSLATION FOR TIE ROD TESTING.

THESE BASIC CONCEPTS AND HARDWARE WILL BE COMBINED TO PRODUCE A TEST RIG WHICH WILL SUBJECT THE SUPPORT STEM ASSEMBLY TO SIMULATED AXIAL, BENDING AND DYNAMIC LOADS.

V/G No. 6 Combined Load Test Rig

18 DRUM TEST RIG

THE NERVA REACTORS WILL INCORPORATE CONTROL DRUMS SIMILAR TO THOSE USED IN PREVIOUS REACTORS. HOWEVER, THE NUMBER OF DRUMS USED PER REACTOR WILL INCREASE, AND A METHOD OF GANGING A NUMBER OF DRUMS TO OPERATE FROM A SINGLE ACTUATOR WILL BE INCORPORATED. TESTS OF THE GANGED DRUM REACTOR COMPONENTS AND SYSTEM WILL BE CONDUCTED IN AN 18 DRUM RIG SIMILAR TO THE THREE DRUM RIG SHOWN. THESE WILL EVALUATE THE COMPLETE CLOSED LOOP SYSTEM AND DEMONSTRATE THAT THE SYSTEM WILL FUNCTION AS REQUIRED AT CONDITIONS IN EXCESS OF REACTOR LOAD AND TEMPERATURE.

THE TEST FIXTURE WILL ACCOMMODATE THE R1 DECOUPLER COMPONENTS AND WILL BE SIZED TO THE R1 GEOMETRY. SIX, EQUALLY SPACED, HYDRAULIC ACTUATORS WILL BE USED FOR THE EARLY TESTS. AND PROVISIONS HAVE BEEN MADE TO INCORPORATE PNEUMATIC ACTUATORS FOR THE PREQUALIFICATION AND QUALIFICATION TESTS. DUMMY DRUMS OF THE SAME MASS AND INERTIA AS THE R1 DRUMS WILL BE PART OF THE SYSTEM. LOAD DEVICES TO SIMULATE DRUM PRESSURE DROP LOADS AND BRAKES TO LOCK DRUMS TO SIMULATE STICKING WILL BE INCORPORATED TO INPUT ACTUAL OPERATING LOAD CONDITIONS TO THE GANGED DRUM DRIVE SYSTEM. OPERATION AT CRYOGENIC TEMPERATURE WILL BE BY IMMERSION OF THE SYSTEM COMPONENTS IN LIQUID NITROGEN.

THE SAME TEST RIG WILL BE USED TO CONDUCT DRUM TORQUE AND ROTATION TESTS AS PART OF THE REFLECTOR AND AXIAL SUPPORT SYSTEM TESTING.

V/G No. 7 18 Drum Test Rig

ENGINEERING MECHANICS TEST RIG DESCRIPTION

TRANSIENT TEST RIGS

<u>NAME</u>	<u>COMPONENT TESTED</u>
1. CRYOGENIC THERMAL SHOCK RIG	SHIELD, REFLECTOR & AXIAL SUPPORT
2. HIGH TEMPERATURE THERMAL SHOCK RIG	CHESH, CAMH

CRYOGENIC TEST RIG

THE SHIELD AND REFLECTOR ARE SUBJECT TO SEVERE THERMAL SHOCK ON REACTOR STARTUP. TO VERIFY THAT THE SELECTED GEOMETRY AND MATERIALS ARE CAPABLE OF MAINTAINING THEIR INTEGRITY UNDER THESE CONDITIONS ACTUAL SHIELD ELEMENTS AND SPECIMENS MADE FROM TREPANNED SECTIONS OF THE BERYLLIUM REFLECTOR WILL BE SHOCKED AT RATES MORE SEVERE THAN EXPECTED IN THE REACTOR IN THE CRYOGENIC THERMAL SHOCK RIG SHOWN.

THIS CRYOGENIC LOOP HAS THE ABILITY TO RECIRCULATE GASEOUS HELIUM THROUGH A LIQUID N_2 HEAT EXCHANGER PROVIDING GAS TEMPERATURES OF APPROXIMATELY $150^{\circ}R$. A SECOND HEAT EXCHANGER USING LIQUID HELIUM CAN BE ADDED IN SERIES TO PROVIDE TEMPERATURES AS LOW AS $15^{\circ}R$.

SPECIAL FIXTURING MUST BE DESIGNED TO HOLD THE TEST PIECE AND DIRECT THE GAS FLOW.

V/G No. 8 Cryogenic Thermal Shock Rig

HIGH TEMPERATURE THERMAL SHOCK RIG

V/G No. 9 HIGH TEMPERATURE THERMAL SHOCK RIG

FUEL ELEMENT TIPS AND CLUSTER HOT END SUPPORT HARDWARE MUST BE CAPABLE OF SUSTAINING HEATUP AND COOLDOWN TRANSIENTS IN EXCESS OF $150^{\circ}\text{R}/\text{sec}$. HOT END HARDWARE WILL BE TESTED UNDER CONDITIONS SIMULATING BOTH THE TEMPERATURE AND LOAD ENVIRONMENT DURING REACTOR STARTUP AND SHUTDOWN USING THE HIGH TEMPERATURE THERMAL SHOCK RIG SHOWN.

THIS RIG IS BASICALLY A RESISTANCE HEATED 6" x 54" HIGH TEMPERATURE FURNACE WITH AN AXIAL LOAD CAPABILITY OF 10,000 LB. A 19 ELEMENT CLUSTER SERVES AS A HEAT EXCHANGER WHICH IS USED TO HEAT THE HELIUM GAS WORKING MEDIUM. STARTUP THERMAL SHOCK RATES OF $300^{\circ}\text{R}/\text{SEC}$ TO A TEMPERATURE OF 4500°R HAVE BEEN ACHIEVED. A THERMALLY INSULATED FLOW PATH THRU THE CENTER OF THE HEAT EXCHANGER CLUSTER AND SPECIAL VALVING ALLOWS ALTERNATE COOL DOWN SHOCK SIMULATION WITH COLD HELIUM GAS. COOLING SHOCKS IN EXCESS OF $150^{\circ}\text{R}/\text{sec}$ HAVE BEEN ACHIEVED.

MODIFICATIONS TO THE FURNACE WILL BE REQUIRED TO INCREASE THE MAXIMUM TEMPERATURE CAPABILITY TO 5000°R AND TO INCREASE THE COOLING SHOCK RATE TO AT LEAST 200°R .

ENGINEERING MECHANICS TEST RIG DESCRIPTION

ENVIRONMENTAL TEST RIGS

<u>NAME</u>	<u>COMPONENT TESTED</u>
1. VACUUM CHAMBER TEST RIG	CHESH, CAMH
2. SPECIAL ENVIRONMENT TEST RIGS	ALL

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CLUSTER TEST ARRANGEMENT

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VACUUM CHAMBER TEST RIG

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NERVA ENGINE FLIGHT WILL SUBJECT THE REACTOR TO DIFFERING LEVELS OF VACUUM. THE LEVELS TO BE EXPECTED AND THE FRICTION BEHAVIOR OR MATING PARTS AND THE EFFECTS ON FUEL ELEMENT CORROSION PERFORMANCE UNDER THESE CONDITIONS MUST BE DETERMINED BY TESTING. THE VACUUM TEST RIG SHOWN WILL BE USED TO OBTAIN THIS TYPE OF DATA. THIS SYSTEM IS CAPABLE OF ACHIEVING VACUUM LEVELS OF 10^{-7} TOR IN THE 18" x 30" CHAMBER SHOWN AND CAN MAINTAIN THIS FOR THREE MONTHS CONTINUOUS OPERATION.

SPECIAL FIXTURING OF THE TYPE SHOWN IS DESIGNED AND MUST BE BUILT FOR THE TEST PROGRAM. THIS FIXTURING, USING THE BASIC PUMPING SYSTEM, WILL PROVIDE INTERFACE FRICTION, CORROSION PROPERTIES EFFECTS AND AN ESTIMATE OF THE CONDUCTANCE OF THE CORE.

V/G No. 10 Vacuum Test Rig

SPECIAL ENVIRONMENTAL TEST RIGS

V/G No. 11 SPECIAL ENVIRONMENTAL TEST RIGS

CONSIDERATION MUST BE GIVEN TO THE ENGINEERING CRITICAL COMPONENTS ABILITY TO WITHSTAND THE STORAGE AND LAUNCH PAD ENVIRONMENTAL CONDITIONS WITHOUT AFFECTING THEIR ABILITY TO PERFORM.

SHOWN IS A STANDARD TEST CHAMBER WHICH PROVIDES HUMIDITY AND TEMPERATURE CONTROL TO THE COMPONENT UNDER TEST. SIMILAR CHAMBERS, CAPABLE OF CONTAINING BACTERIA AND FUNGUS CULTURES, CORROSIVE ATMOSPHERES AND INERT STORAGE ATMOSPHERES MUST BE PROVIDED FOR THE NERVA PROGRAM. STANDARD CHAMBERS WILL BE USED WHERE POSSIBLE AND OTHER SPECIAL UNITS WILL BE DESIGNED AS REQUIRED.

ENGINEERING MECHANICS TEST RIG DESCRIPTION
RELATIONSHIP OF TEST RIGS TO ECC REQUIREMENTS

<u>ECC</u>	<u>Para.</u>	<u>Requirement</u>	<u>Type Test Required</u>			<u>Test Rig</u>
677558 Cluster Ass'y & Misc. Hdw.	3.1.1.1.1	Load Support	D	PQ	Q	Hi Temp Bundling Furnace
	3.1.1.1.3	Insulation	D	PQ	Q	Hi Temp Bundling Furnace
	3.1.2.4.1	Operating Environment	D	PQ		Vacuum Chamber Test Rig
					Q	Vibration Core Test Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig
677557 Cluster Hot End Support Hdw.	3.1.1.1.1	Load Support	D	PQ	Q	Hi Temp Bundling Furnace
			D	PQ	Q	Hi Temp Thermal Shock Rig
			D	PQ		Vacuum Chamber Test Rig
	3.1.1.1.4	Cluster Fuel Interaction	D	PQ	Q	Hi Temp Bundling Furnace
	3.1.1.1.5	Malfunctions	D	PQ	Q	Hi Temp Bundling Furnace
	3.1.2.4.1	Operating Environment	D	PQ		Vacuum Chamber Test Rig
					Q	Vibration Core Test Rig
	3.3.1.3	Instrumentation	D	PQ	Q	Hi Temp Bundling Furnace
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig
677556 Support Stem	3.1.1.1.1	Core Support		PQ	Q	Combined Load Test Rig
	3.1.1.1.6	Deflection			Q	Combined Load Test Rig
	3.1.2.4.1	Operating Environment			Q	Vibration Core Test Rig
	3.1.2.5	Transportability		PQ	Q	Combined Load Test Rig
	3.3.1.3	Instrumentation		PQ	Q	Combined Load Test Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig
677566 Fuel Elements	3.1.2.4.1	Operating Environment	D	PQ		Vacuum Chamber Test Rig
					Q	Vibration Core Test Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig

ENGINEERING MECHANICS TEST RIG DESCRIPTION
RELATIONSHIP OF TEST RIGS TO ECC REQUIREMENTS

<u>ECC</u>	<u>Para.</u>	<u>Requirement</u>	<u>Type Test Required</u>			<u>Test Rig</u>
677564 Core Periphery	3.1.1.1.2	Bundling Loads	D	PQ	Q	Hi Temp Horizontal Rig
	3.1.1.1.3.1	Radial Flow	D	PQ	Q	Hi Temp Horizontal Rig
	3.1.2.4.1	Operating Environment			Q	Vibration Core Test Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig
677563 Lateral Support System	3.1.1.1.1	Lateral Restraint	D	PQ	Q	Partial Core Test Rig
	3.1.2.4.1	Operating Environment			Q	Vibration Core Test Rig
	3.3.1.3	Instrumentation	D	PQ		Partial Core Test Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig
677559 Reflector & Axial Support	3.1.1.1.2	Axial Support	D	PQ	Q	Axial Support Static Load Rig
			D	PQ		Cryogenic Thermal Shock Rig
	3.1.1.1.3	Radial Support	D	PQ	Q	Axial Support Static Load Rig
			D	PQ		Cryogenic Thermal Shock Rig
	3.1.1.1.6	Control Drum Rotation	D	PQ	Q	18 Drum Test Rig
	3.1.1.1.7	Drum Torque	D	PQ	Q	18 Drum Test Rig
	3.1.2.4.1	Operating Environment			Q	Vibration Core Test Rig
	3.3.1.3	Instrumentation	D	PQ	Q	Axial Support Static Load Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig

ENGINEERING MECHANICS TEST RIG DESCRIPTION
RELATIONSHIP OF TEST RIGS TO ECC REQUIREMENTS

<u>ECC</u>	<u>Para.</u>	<u>Requirement</u>	<u>Type Test Required</u>			<u>Test Rig</u>
677560 Ganged Drum Drive System	3.1.1.1.1	Drum Positioning	D	PQ	Q	18 Drum Test Rig
	3.1.1.1.2	Backlash	D	PQ		18 Drum Test Rig
	3.1.1.1.3	Torque Transmission & Decoupling	D	PQ	Q	18 Drum Test Rig
	3.1.1.1.4	Drum Rates	D	PQ	Q	18 Drum Test Rig
	3.1.1.2.1	Malfunctions	D	PQ	Q	18 Drum Test Rig
	3.1.2.4.1	Operating Environment			Q	Vibration Core Test Rig
	3.1.2.5	Transportability	D	PQ	Q	18 Drum Test Rig
	3.1.2.7	Safety	D	PQ	Q	18 Drum Test Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig
677562 Shields	3.1.2.4.1	Operating Environment			Q	Vibration Core Test Rig
	3.3.3	Mtls., Parts & Proc.		PQ		Cryogenic Thermal Shock Rig
	3.3.5	Moisture & Fungus	D		Q	Special Environmental Test Rig

ENGINEERING MECHANICS TEST RIG DESCRIPTION

SUMMARY

- 1) THREE GENERAL TYPES OF TEST TO BE CONDUCTED:
 - A) DEVELOPMENT
 - B) PRE-QUALIFICATION
 - C) QUALIFICATION
- 2) TESTS IN THE ENGINEERING MECHANICS LABORATORY WILL INVOLVE THE APPLICATION OF STATIC AND/OR DYNAMIC LOADS TO MECHANICAL COMPONENTS AT STEADY STATE AND TRANSIENT TEMPERATURES RANGING FROM 15°R TO 5000°R, UNDER THE APPROPRIATE GASEOUS OR VACUUM CONDITIONS.
- 3) APPROXIMATELY 350 INDIVIDUAL TESTS HAVE BEEN DEFINED AS PART OF THE TEST PROGRAM TO VERIFY THAT THE COMPONENTS WILL MEET THE ECC SPECIFICATION REQUIREMENTS.
- 4) APPROXIMATELY 24 MAJOR RIGS WILL BE REQUIRED TO IMPOSE THE CONDITIONS THAT WILL DEMONSTRATE AND VERIFY THAT SPECIFICATION REQUIREMENTS CAN BE MET UNDER TRANSIENT AND MARGIN CONDITIONS. AS SHOWN BY THE TEST RIGS THAT WERE DESCRIBED, SOME EXIST IN USABLE FORM, SOME WILL BE BUILT BY MODIFYING EXISTING EQUIPMENT . AND SOME WILL REQUIRE COMPLETE DESIGN AND FABRICATION.

THERMO-FLOW LABORATORY FACILITY REQUIREMENTS

- I. TEST AREAS COVERED BY THERMO-FLOW LABORATORY.
- II. DESCRIPTION OF FACILITIES.
- III. SUMMARY OF THE FACILITIES AND THE RELATION TO VARIOUS TESTS.

I. TEST AREAS COVERED BY THERMO-FLOW LABORATORY

- A. GRAPHITE - HYDROGEN - CORROSION
- B. GRAPHITE COATING INTEGRITY
- C. THERMAL EFFECTS
- D. FLOW IMPEDANCE CHARACTERISTICS
- E. SEAL EFFECTIVENESS
- F. HEAT TRANSFER

II. FACILITIES DESCRIPTION

- A. SINGLE ELEMENT CORROSION TEST FACILITIES
- B. SINGLE CLUSTER TEST FACILITY
- C. FILLER STRIP TEST FACILITY
- D. FLOW TEST FACILITIES
- E. CORROSION TEST FACILITIES

SINGLE ELEMENT CORROSION TEST FACILITY

		PRESENT CAPABILITY	** ECC REQUIREMENT	FUTURE CAPABILITY
INLET GAS TEMPERATURE	(°R)	AMBIENT	290	140
EXIT GAS TEMPERATURE	(°R)	5000 MAX.	≈ 5000	5000 MAX.
EXIT GAS PRESSURE	(PSIA)	800 MAX.	450	800 MAX.
HYDROGEN MASS FLOW RATE	(LB/SEC)	0.075 MAX	0.051	0.075 MAX.
POWER	(MW)	3 MAX.	0.9	3 MAX.
TEST TIME		AS REQUIRED	AS REQUIRED	AS REQUIRED

** PRESENT ESTIMATES OF 3 σ REQUIREMENTS AND NOT FINAL REQUIREMENTS

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SINGLE ELEMENT CORROSION TEST FACILITY

ECC.	PARAGRAPH	TEST TITLE	DEV.	PRE-QUAL.	QUAL.
677566 FUEL ELEMENTS	3.1.1.1.2	THERMAL AND FLOW CHARACTERISTICS	X		
	3.1.1.1.3	TEMPERATURE VARIATION	X		
	3.1.1.1.5	CORROSION AND REACTIVITY LOSS	X	X	X
	3.1.2.5	TRANSPORTABILITY	X		
	3.3.1.3	INSTRUMENTATION	X		
	3.3.5	MOISTURE AND FUNGUS RESISTANCE	X		
	3.3.6	CORROSION OF PARTS	X	X	X
	3.3.11	STORAGE	X		

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SINGLE CLUSTER FACILITY

		PRESENT CAPABILITY	** ECC REQUIREMENT	FUTURE CAPABILITY
INLET GAS TEMPERATURE	(°R)	AMBIENT	290	CRYOGENIC
EXIT GAS TEMPERATURE	(°R)	5000	5000	5000
EXIT GAS PRESSURE	(PSIA)	800 MAX.	450	800 MAX.
HYDROGEN MASS FLOW RATE	(LB/SEC)	0.2	0.3	0.5
POWER	(MW)	2.8	6.0	9.0
TEST TIME		AS REQUIRED	AS REQUIRED	AS REQUIRED

** PRESENT ESTIMATES OF 3 σ REQUIREMENTS AND NOT FINAL REQUIREMENTS.

SINGLE CLUSTER TEST FACILITY

ECC	PARAGRAPH	TEST TITLE	DEV.	PRE-QUAL.	QUAL.
677556	3.1.1.1.1	CORE SUPPORT	X	X	X
SUPPORT	3.1.1.1.2	FLUID PASSAGE	X	X	X
STEM	3.1.1.1.4	ORIFICING	X	X	X
ASSEMBLY	3.3.1.3	INSTRUMENTATION	X	X	X
	3.3.6	CORROSION OF PARTS	X	X	
677557	3.1.1.1.1	CLUSTER LOAD SUPPORT	X	X	X
CLUSTER	3.1.1.1.2	HOT END SUPPORT FLOW	X	X	X
HOT END		CHARACTERISTICS			
SUPPORT	3.1.1.1.3	INSULATORS	X	X	X
HARDWARE	3.1.1.1.4	INTERACTION OF CLUSTER	X	X	X
	3.1.1.1.5	MALFUNCTION	X	X	X
	3.3.1.3	EXIT THERMOCOUPLE TEST		X	X
	3.3.6	CORROSION OF PARTS	X	X	X
677558	3.1.1.1.4	CLUSTER INTERSTITIAL CORROSION	X	X	X
CLUSTER	3.1.1.1.11	MALFUNCTION	X	X	X
ASSEMBLY &	3.3.1.3	INSTRUMENTATION	X	X	X
MISC.	3.3.6	CORROSION OF PARTS	X		
HARDWARE					
677567	3.1.1.1.3	POISON WIRE & CLUSTER INTERACTION	X	X	X
ANTI- CRITICALITY POISON WIRE SYSTEM

612549-1C

FILLER STRIP FACILITY

		PRESENT CAPABILITY	** ECC REQUIREMENT	FUTURE CAPABILITY
INLET GAS TEMPERATURE	(°R)	530	290	140
OUTLET GAS TEMPERATURE	(°R)	1600	1572	1600
INNER WRAPPER TEMPERATURE	(°R)	4750	5000	5000
OUTER WRAPPER TEMPERATURE	(°R)	3000	2580	2580
EXIT GAS PRESSURE	(PSIA)	450	450	450

** PRESENT ESTIMATES OF 3 σ REQUIREMENTS AND NOT FINAL REQUIREMENTS.

FILLER STRIP TEST FACILITY

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ECC	PARAGRAPH	TEST TITLE	DEV.	PRE-QUAL.	QUAL.
677564	3.1.1.1.2	BUNDLING LOADS	X	X	X
CORE	3.1.1.1.3.1	RADIAL FLOW	X	X	X
PERIPHERY	3.1.1.1.3.2	AXIAL FLOW	X	X	X
	3.1.1.1.6	WRAPPER EXPANSION	X	X	X
	3.3.1.3	INSTRUMENTATION	X	X	X
	3.3.6	CORROSION OF PARTS	X	X	X

FLOW TEST FACILITY

ECC	PARAGRAPH	TEST TITLE	DEV.	PRE-QUAL.	QUAL.
677556 SUPPORT STEM ASSEMBLY	3.1.1.1.4	SUPPORT STEM ASSEMBLY ORIFICING	X	X	X
677558 CLUSTER ASSEMBLY & MISC. HARDWARE	3.1.1.1.3 3.1.1.1.6 3.1.1.1.7 3.1.1.1.8 3.1.1.1.8	CLUSTER ASSEMBLY THERMAL TEST ELEMENT FLOW SCREENING STEM FLOW PASSAGE-SEAL LEAKAGE FUEL ELEMENT-ORIFICE IMPEDANCE FLOW METERING-ORIFICE BRAZE	X X X X X	X X X X	X
677559 REFLECTOR & AXIAL SUPPORT	3.1.1.1.4 3.1.1.1.5 3.3.1.3	RASS - RADIAL LEAKAGE SEAL TESTS RASS - FLOW CHARACTERISTICS INSTRUMENTATION	X X X	X X	X X
677561 SUPPORT STEM FEED & DIS- CHARGE SYSTEM	3.1.1.1.1 3.1.1.1.3 3.1.1.1.4 3.1.1.1.8 3.3.1.3	SSF & DS FLOW CHARACTERISTICS SSF & DS SEAL LEAKAGE SSF & DS AXIAL FLOW CHARACTERISTICS MIXING CHAMBER TEMP. VARIATION INSTRUMENTATION	X X X X X	X X X X	X X X X
677562 SHIELDS	3.1.1.1.4 3.3.1.3	FLOW DISTRIBUTION & PRESSURE DROP INSTRUMENTATION	X X	X X	 X
677563 LATERAL SUPPORT SYSTEM	3.1.1.1.4 3.1.1.1.5 3.1.1.1.6 3.3.1.3	LSS FLOW CHARACTERISTICS INSULATION EFFECTIVENESS LSS FLOW CHARACTERISTICS INSTRUMENTATION	X X X X	X X X	X X X
677566 FUEL ELEMENT	3.1.1.1.7 3.1.1.1.8	ELEMENT TIP INTEGRITY ELEMENT POROSITY	X X	X X	 X

CORROSION TEST FACILITY

ECC	PARAGRAPH	TEST TITLE	DEV.	PRE-QUAL.	QUAL.
677558	3.1.1.1.4	CLUSTER INTERSTITIAL CORROSION	X		
CLUSTER	3.3.1.3	INSTRUMENTATION	X	X	X
ASSEMBLY & MISC. HARDWARE	3.3.6	CORROSION OF PARTS	X	X	X
677559	3.3.6	CORROSION OF PARTS	X	X	X
REFLECTOR & AXIAL SUPPORT SYSTEM					
677562	3.3.6	CORROSION OF PARTS	X	X	X
SHIELDS					
677563	3.3.6	CORROSION OF PARTS	X	X	X
LATERAL SUPPORT SYSTEM					
677564	3.1.1.1.3	WRAPPER AXIAL CORROSION RESISTANCE	X	X	X
CORE	3.1.1.1.4	CORE PERIPHERY THERMAL IMPEDANCE	X		
PERIPHERY	3.3.6	CORE PERIPHERY CORROSION	X	X	X

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