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SUMMARY OF PROJECT NE 1840 STATUS REVIEW
PRESENTATION AT SNPO-C - AUGUST 11, 1964

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I. NERVA II REACTOR DESIGN

Introduction

Soon after the initiation of the Project NE 1840 in May, WANL contacted LASL and discussed various features of PHOEBUS II reactor design. WANL effort in the NERVA II reactor sizing and design has been based on the following ground rules:

1. Select the largest core diameter which still allows peripheral control as in NRX-A reactors.
2. Conservative extrapolation of the present NRX-A reactor technology.

The control drum reactivity worth versus core diameter as a function of void fraction was estimated on the basis of one-dimensional diffusion theory as shown on Curve No. 602624VG. Point check was made with two-dimensional analysis and verified. It is evident that the core diameter is strongly influenced by the void fraction.

Fuel element size of NRX-A was retained except in the flow hole diameter which was increased to 0.115". This resulted in the core void fraction of about 0.40. Next, selecting somewhat arbitrarily criteria of the minimum drum worth of about \$9.00, as for the NRX-A reactor, the core diameter of 59" was selected.

Comparison of PHOEBUS II and NERVA II reactor characteristics are shown on Table No. 1. Many of PHOEBUS II features are results of LASL's early study effort in a flexible reactor for the power range of 5000 - 8000 MW, such as 12-sided core shape, torsion bar lateral support spring, and nozzle chamber pressure of 625 psia, etc.

Mechanical design effort has been primarily concentrated in areas of integrated reflector structure, lateral support spring and seal ledge, counterflow tie tube for cluster assembly, and core support plate and tie tube coolant mixing.

A. Integrated Reflector

Curves Nos. 602655VG and 602654VG show the plan and elevation views of reflector design Scheme 1. It is made up from two separate structures. The outer structure consists of two large concentric cylinders connected by means of 24 control drum housing tubes. The inner structure is provided with support ledges for segmented axial seals. The

two structures are bolted together with 1/8 " gap between them for seal ledge coolant flow. Assembly is rather complex and requires hand fitting jobs for proper spacing.

Curves Nos. 602662VG and 602653VG show the plan and elevation views, respectively, of design Scheme 2. In this design, the outer structure is shrunk on the inner structure, then the plunger pin holes drilled, and the two structures bolted. Seal ledge coolant flow slots and axial ribs are milled on the O.D. of the inner structure prior to the shrink fit assembly. Assembly is considerably simpler than the Scheme 1, and avoids quilting of the inner structure when bolted.

Curves Nos. 602658VG and 602657VG show two views of design Scheme 3. This is identical to Scheme 2, except that the seal ledge coolant flow paths are provided by axial drilled holes rather than milled ribs. This design provides smooth interface between the inner and outer structures for the shrink fit assembly.

Design Scheme 4 shown on Curves Nos. 602661VG and 602672VG departs from the other schemes in that the stiffening of the inner structure is accomplished by four transverse flanges. Drum housing does not partake lateral stiffening of the reflector structure.

Lateral support spring arrangement shown in Scheme 4 enables easy assembly of core and reflector. In order to accommodate differential thermal expansion between beryllium and aluminum, the long plunger pin is made in two sections, with graphite pin contact with the seal ring, while the aluminum pin transmits spring load. The same spring arrangement can be adopted for the other three design schemes.

The preferred reflector structural design will be made soon between Schemes 3 and 4.

B. Counterflow Tie Tube Flow System

To improve specific impulse without raising the maximum fuel element temperature of 4277°R , use of counterflow tie tube arrangements was adopted. Two areas of concern were: 1) method of pressure head supply for tie tube coolant flow, and 2) temperature mixing of the tie tube effluent.

Three alternatives of obtaining the necessary pressure head have been

considered and they are to utilize a) the pressure drop across the core support plate, b) the pressure drop across reflector and shield, and c) the pump discharge pressure by separate supply line from the pump discharge line.

The second area of concern stems from the fact that the outlet temperature of an orificed core is rather sensitive to the variation of inlet temperature. NRX-A reactor analysis indicated the temperature magnification of six or seven, i.e., for $\pm 10^\circ \text{R}$ variation at inlet, results in about ± 60 to 70°R at outlet. Preliminary estimate indicates about 800°R for tie tube effluent at core center while the bulk of propellant enters at about 240°R . Consequently, several coolant mixing schemes were considered and they are: a) mixing jets with series baffle plates, c) mixing jet with radial flow baffle, and d) discharge of tie tube effluent into reflector outlet.

Four different flow schematics, combining the aforementioned pressure supplies and temperature mixing, are shown on the following view graphs:

Scheme 1 (Curve No. 602663VG) is the simplest arrangement using pressure drop across the support plate as driving pressure and simple mixing jet at the tube outlet. It is rather inflexible and requires additional pump head. Temperature mixing is not too assuring.

Scheme 2 (Curve No. 602669VG) shows utilizing pressure drop across the reflector and shield and radial flow baffle for temperature mixing. Internal mechanical design will be somewhat complex, although this scheme does not require additional pump head. Temperature mixing will be quite good.

Scheme 3 (Curve No. 602664VG) shows external supply header and series of baffle plates. This scheme provides operational flexibility and large supply pressure head. Temperature mixing scheme is probably not as good as radial flow baffle since core inlet fluid will have a radial temperature gradient with this arrangement.

Scheme 4 (Curve No. 602665VG) shows external supply line at centerline of the dome, and the tie tube effluent is discharged into the reflector outlet.

Temperature mixing is accomplished by means of a long flow path through the

shield and core support plate. This arrangement appears to be the most promising among those we have considered.

C. Counterflow Tie Tube Design

General arrangement and design features are shown on Curve No. 602671VG. Coolant flows from the inlet plenum chamber above the core support plate (dome end side of core support plate) through the inner tube, turn 180° at button end within support block, flows through annulus formed by the concentric inner and outer tubes, then discharge into the plenum chamber under the core support plate (between core support plate and core inlet). This sketch shows the radial flow baffle plate. Details at various regions are shown on Curves Nos. 602652VG and 602660VG. The installation of the tie tube to the core support plate uses identical methods as used for the NRX-A reactor tie rod. The inner tube is the load carrying member. The heavy threaded end of the inner tube can be obtained either by brazed on sleeve or by roll forming of a heavy wall tube. The lower end of the inner tube is flared cone shape. Load from the support block is transmitted by a cruciform conical sleeve over the inner tube flared end. A cruciform piece is inserted into the flared end to prevent flare from collapsing. Welded construction is contemplated.

Tie tube coolant supply plenum and through flow path (for bulk of coolant flow) with spacer tube are shown on Curve No. 602650VG.

D. Heat Transfer Analysis at Seal Ledge

The present design concept eliminated the graphite inner reflector, and the aluminum inner structure of the integrated reflector comes in close proximity to the core periphery. Proper cooling of the seal ledge has been identified as one of the areas with which to be concerned. The model used for the heat transfer analysis is shown on Curve No. 602651VG. Estimated values of heat transfer coefficients between core and seal, between seal, between seal and ledge, and at coolant side ledge corner are used. Many of these are difficult to estimate, and it was necessary to use conservative values. Results are tabulated on Table No. 2. The first two cases are interesting to compare. Very conservative estimates of heat transfer coefficients are used in both cases. This result indicated the desirability of developing coolant core periphery designs. For comparison,

cooled periphery design and NRX-A5 at station 52 are also tabulated.

E. Filler Strip Tie Tube

One of the cooled periphery designs is to use a two-pass tie tube within filler strips. Coolant supply and effluent mixing will be common with core tie tubes. Curve No. 602684VG shows conceptual design of tie tube arrangement, coolant flow into the core through the center tube, 180° turn at filler strip support block, and two adjacent tubes to discharge plenum. No detailed mechanical design has been developed at present.

II. SUPPORT OF STL EFFORT IN NOP

WANL methodology in nuclear, shield, thermal, and structural analysis of the NERVA reactor was discussed and shown to STL personnel on June 11 and June 12, 1964, at WANL. In addition, WANL transmitted the following technical reports to STL:

WANL-TNR-002
WANL-TNR-045
WANL-TNR-128 (3 volumes)
WANL-TME-224
WANL-TME-239
WANL-TME-273
WANL-TME-330
WANL-TME-483
WANL-TME-484
WANL-TME-618
WANL-TME-636
WANL-TME-711
WANL-TME-743

The curve of reactor weight versus thrust for core diameters of 35", 45", and 55" was generated and shown on Curve No. 602686VG. Corollary data of "thrust versus core diameter" and "thrust to weight ratio versus weight" were prepared and shown on Curves Nos. 602674VG and 602711VG, respectively. The latter curve is interesting in that the curve for NRX-A power density passes through the maximum value of thrust to

weight ratio for the 45" diameter core, while the curve for PHOEBUS power density keeps increasing as the reactor weight increases. As the reactor size was scaled up, some components reach the limit of the presently available technology, and departure from the present NRX-A design occurs. A good example of this is the use of the graphite inner reflector. The maximum O.D. fabricable with comparable quality is about 58" diameter. This leads to design consideration of a reflector with aluminum structure, without a graphite reflector. This, in turn, affects the beryllium thickness required for a given control span. Results are shown on Curve No. 602712VG. There is a crossover point near the core diameter of 45".

EFFECT OF CORE DIAMETER AND VOID FRACTION ON CONTROL

602624VG

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TABLE 1

LASL AND WANL 5000 MW REACTORS

	<u>PHOEBUS II</u>	<u>NERVA II</u>
CORE PARAMETERS		
Thrust	230,000 lb	233,000 lb
Total Power	5000 MW	5000 MW ₃
Power Density	70 MW/ft ³	61 MW/ft ³
Fueled Diameter	55"	59"
Overall Diameter	77"	79.750"
Fuel Element Length	52"	52"
Peak Loading Density	390 mg/cc	400 mg/cc
U Inventory	~ 320 kg	~ 370 kg
Core Pressure Drop	150 - 160 psi	98 psi
Radial Power Peak/Ave.	< 1.2	< 1.2 design goal
Fuel Channel Exit Gas Temperature	4500°R	4280°R
Mixed Exit Gas Temperature	4500°R	4280°R
Exit Gas Mass Rate	285 lb/sec	297 lb/sec
Specific Impulse	805 sec	785 sec
Core Perimeter	12-sided	Circular
Lateral Support Force Source	8" Torsion Bars	Coil Springs
Peripheral Interface Structural Material	Al	Al
REFLECTOR CHARACTERISTICS		
Beryllium Thickness	7 1/2"	7 1/8"
Number of Control Drums	18	24
Control Span	\$8 - \$10 est.	\$9 est.
Control System	Rotating B ¹⁰ -Al tubes	Rotating B ¹⁰ -Al plated drums
FUEL ELEMENTS		
Number		4635 Fueled 799 Unfueled
Geometry	19 hole hexagonal	19 hole hexagonal
Size Across Flats (Hexagon Shape)	0.754"	0.754"
Reamed Hole Size	0.110"	0.115"
Coating	1 1/2 - 2 mils NbC	1 mil NbC
Interior Web Thickness	0.058"	0.0524"
Peripheral Wall Thickness	0.030"	0.0300"
Void Fraction	34%	40%

602731VG

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**INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT
SCHEME 1 PLAN VIEW**

602655VG

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**INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT — SCHEME 1 AXIAL VIEW**

602654VG

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**INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT-SCHEME 2 PLAN VIEW**

602662VG

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**INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT- SCHEME 2 AXIAL VIEW**

602653VG

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**INTEGRATED REFLECTOR AND LATERAL
SUPPORT ARRANGEMENT
SCHEME 3 PLAN VIEW**

602658VG

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**INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT - SCHEME 3 AXIAL VIEW**

602657V0

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INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT

SCHEME 4 PLAN VIEW 602661VG

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INTEGRATED REFLECTOR AND LATERAL SUPPORT
ARRANGEMENT - SCHEME 4 AXIAL VIEW

602672VG

SCHEME 1
COUNTERFLOW TIE TUBE FLOW SCHEMATIC

SCHEME 2
COUNTERFLOW TIE TUBE FLOW SCHEMATIC

SCHEME 3
COUNTERFLOW TIE TUBE FLOW SCHEMATIC

SCHEME 4
COUNTERFLOW TIE TUBE FLOW SCHEMATIC

602671VG

COUNTER FLOW TIE TUBE ARRANGEMENT DETAILS

602652VG

COUNTERFLOW TIE TUBE ARRANGEMENT DETAILS

602660VG

**COUNTERFLOW TIE TUBE COOLANT
SUPPLY PLENUM DETAIL**

602650VG

MAXIMUM GRAPHITE HEAT GENERATION = $1.25 \times 10^7 \text{ BTU/hr ft}^3$

NERVA II THERMAL ANALYSIS OF ALUMINUM REFLECTOR SUPPORT CORE STATION 26

602651VG

TABLE 2
SUMMARY TABLE
ALUMINUM REFLECTOR SUPPORT

CASE (Sta. 26 unless noted)	SEAL T_b h	BETWEEN SEAL T_b h	ALUMINUM T_b h	CORNER T_b h	CONTACT COEFFICIENT	MAXIMUM AL TEMPERATURE
Hot Periphery	3000 10^6	2000 150	230 1740	230 400	2000	1719
Cooled Periphery	1000 10^6	1000 10^6	230 1740	230 400	2000	1018
Cooled Periphery	500 1500	500 150	230 1740	230 1740	220	460
Cooled Periphery (Sta. 52)	750 1500	750 150	150 1740	150 1740	220	287
Cooled Periphery	500 1500	500 150	230 1740	230 1740	2000	601
Cooled Periphery (Sta. 52)	750 1500	750 150	150 1740	150 1740	2000	395
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 400	220	1051
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 400	1000	1267
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 400	2000	1340
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 1740	220	638
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 1740	1000	805
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 1740	2000	869
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 3000	220	550
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 3000	1000	700
NRX-A5 Periphery	2000 3300	2000 150	230 1740	230 3000	2000	758

$$h = \text{BTU/hr ft}^2 \text{ } ^\circ\text{R}, T_b = ^\circ\text{R}$$

602730 VG

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602684VG

FILLER STRIP COUNTERFLOW TIE TUBE ARRANGEMENT

WEIGHT VS THRUST

602686VG

THRUST VS CORE DIAMETER

602674VG

THRUST TO WEIGHT RATIO VS WEIGHT

602711VG

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NOTES.

35 INCH CORE HAS 12 DRUMS
AND .29 VOID FRACTION
45 INCH CORE HAS 18 DRUMS
AND .34 VOID FRACTION
55 INCH CORE HAS 24 DRUMS
AND .39 VOID FRACTION
 $K_{out} = 1.05$

Be THICKNESS VS CORE DIAMETER FOR \$8.70 DRUM SPAN

602712VG

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