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WANL-TME-063
MAY, 1962

TME 063

B-1 AND B-2
REACTOR DESIGN SUMMARY
(Title Unclassified)

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Westinghouse Electric Corporation

Astronuclear Laboratory

Box 10864, Pittsburgh 36, Pa
Telephone HObart 6-6800

August 3, 1962

*
Mr. R. Wilke
Space Nuclear Propulsion Office
Lewis Research Center
21000 Brookpark Road
Cleveland 35, Ohio

Dear Mr. Wilke:

Transmitted herewith are one (1) copy each of the following classified documents and drawings:

WANL-TME-059	Summary of Nuclear Information for Preliminary B-1 Flight Design
WANL-TME-063	B-1 and B-2 Reactor Design Summary
WANL-TME-094 <i>John Smith</i> <i>4/9/62</i>	Preliminary Description of NRX-A1 Reactor Regions for Neutronic Calculations
WANL Drawing No. 553502	NRX-A1 Reflector and Lateral Support
WANL Drawing No. 934J534	NRX-A for CURE Input
WANL Drawing No. 934J575	Layout NRX-A1 Based on B-4 Reactor

These documents and drawings are transmitted for your information per your request.

Respectfully,

H. F. Faught
Program Manager
NERVA Nuclear Subsystem

jm

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B-1 AND B-2 REACTOR DESIGN SUMMARY

SPECIAL REVIEW FINAL DETERMINATION	Reviewer	Class.	Date
	KAW	U	5-482
Class: <u>U</u>			

Classification cancelled (or changed) to
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B-1 AND B-2 REACTOR DESIGN SUMMARY

1.0 INTRODUCTION

Analysis of the B-1 and B-2 reactors during NERVA Phase I was reported in WANL-TNR-004. To complete the preliminary reactor designs, steady-state analysis of the heated bleed reactor was continued. The additional thermal design effort was directed toward the adjustment of flow distribution in the reflector flow system and the cores to provide more desirable NERVA reactor designs than developed during Phase I. The design data summarized in this report should not be interpreted as final NERVA flight engine thermal design information. Many significant parts have not been investigated. Further detailed thermal design is required if the B-1 or B-2 type core is chosen for the final NERVA engine design.

The effect of the redesign of the NERVA reactors as described herein on the transient startup and decay heat operating characteristics was not determined.

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2.0 COMPUTATIONAL METHODS

Core Design II and Core Design III computer programs used to determine the flow and temperature distributions reported in WANL-TNR-004 have been updated and improved as new codes MUCAP (Multiple Channel Analysis Program) and SCAP (Single Channel Analysis Program) respectively. The basic fluid flow and heat transfer equations were retained, but options were provided so that a greater variety of design problems could be handled more efficiently. The SCAP code is described in WANL-TNR-045.

The MUCAP and SCAP codes are currently using the hydrogen properties reported in WANL-TNR-043. Revision of these properties will be made and will be kept current with the industry standards on hydrogen properties being recommended by the National Bureau of Standards Laboratory in Boulder, Colorado.

MUCAP was used to analyze the fluid flow and temperature distributions in the core. Required input parameters consist of inlet temperature, axial and radial power shapes, and geometry factors (channel diameters, spacing and type of array). The desired coolant exit temperature, total flow rate, and exit pressure are specified. The output consists of maximum fuel temperature, channel wall temperature, coolant temperature, heat flux, and pressure at incremental positions along the channel length for each parallel channel. Among other options, the program can calculate the channel diameters or orifice loss coefficients needed to produce a uniform radial exit hydrogen temperature.

For use with MUCAP, the cores were subdivided into radial regions with approximately equal heat flux into each channel in the region (as defined by the radial power and channel diameter). All channels within each section had the same diameter.

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The computer model of the reflector and lateral support for analysis with MUCAP consists of circular flow channels, each surrounded by a given amount of heat generating material. This model is defined by assuming adiabatic surfaces within the reflector in such a way that all the heat generated within the volume enclosed by the adiabatic surfaces is removed by the coolant flow through the channel within the adiabatic surfaces. When the coolant passage is an annular passage, equivalent circular flow channels are determined using the hydraulic diameter and maintaining the same total flow area. The number and arrangement of the adiabatic surfaces is dependent upon the particular design being studied.

MUCAP input parameters for reflector analysis are heat flux associated with each parallel channel, geometry factors, and inlet coolant temperature and pressure. For a specified total flow rate, the wall temperature, coolant temperature and flow distributions are computed.

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3.0 REFLECTOR AND LATERAL SUPPORT SYSTEM

The results of the NERVA B-1 and B-2 analyses made during Phase I indicated that revisions in the flow distribution were necessary to obtain a more uniform material temperature and gas exit temperature, thus reducing thermal gradients in the reflector flow system. Therefore, further thermal design effort has consisted of redesigning the flow passages. The method of analysis was similar to that presented in WANL-TNR-004, with the exception that the more versatile MUCAP code was used instead of Core Design II and Core Design III codes.

In addition to revision in flow areas, the lateral support has been redesigned to eliminate the lateral support coolant flow bypassing the core. This flow now is directed through the lateral support coolant channels and exits into the reflector exit plenum. The result of this redesign improves the thermal performance of the engine.

The internal heat generation rate in the reflectors as shown at station + 25.25 (25.25 inches from the inlet face of the core) in Figure 1 remained the same as used for the reflector analysis reported in WANL-TNR-004, Figure 3.20. Figure 2 showing the axial variation in reflector heating rate is equivalent to Figure 3.21 of WANL-TNR-004. The hydrogen flow rate through the cores was maintained at 70 lb/sec. The flow rate entering the NERVA B-1 reflector was then fixed at $70 + 4.6 = 74.6$ lb/sec. The 4.6 lb/sec flow is that bled off through the shield of the heated bleed cycle. For the NERVA B-2 the reflector flow was $70 + 4.6 + .5 = 75.1$ lb/sec. The .5 lb/sec flow was the flow through the B-2 lateral support assembly.

3.1 NERVA B-1 REFLECTOR AND LATERAL SUPPORT

Figure 3 shows a cross sectional view of the redesigned NERVA B-1 reflector and lateral support system with the numbers of the coolant channels and hot spots referred to in the subsequent discussion of thermal design.

The changes made in the reflector flow system as a result of NERVA Phase I design activity consisted of:

1. Reducing the number of holes in the control drum to 7 per drum, (coolant channel 9, Figure 3).
2. Increasing the width of the boral control strip annuli to 0.125 inches on each side, (coolant channel 12, Figure 3).
3. Increasing the annular width between the reflector and pressure vessel to 0.125 inches for thermal expansion and adding an impedance ring to control the coolant flow, (coolant channel 2, Figure 3).
4. Relocating the coolant holes in the reflector, (coolant channels 5, 6, 7, and 8, Figure 3).
5. Adding an impedance ring in the annulus between the control drum aluminum cylinder and beryllium reflector, (coolant channels 10 and 11, Figure 3).
6. Adding an impedance ring in the annulus between the beryllium and lateral support, (coolant channel 1, Figure 3).

It should be noted that impedance rings added are similar to those currently being used by LASL in the KIWI series reactors for coolant flow control.

Table I summarizes the flow channel information for the NERVA B-1 as reported in WANL-TNR-004. Table II summarizes the flow channel information as subsequently redesigned for more uniform temperatures. Table III summarizes the materials comparison of the cross sectional area of the reflector considered in Phase I, WANL-TNR-004 and the reflector redesign reported herein.

The computer model of the reflector for analysis with MUCAP consists of circular flow channels surrounded by a given amount of heat generating material. Table IV summarizes the computer model assumed for the redesign of the reflector. For non-circular flow passages, equivalent circular channels are used where the diameters are obtained from the hydraulic diameter analogy:

$$D_e = \frac{4A}{P} \text{ (in.)}$$

$$A = \text{flow area (in}^2\text{)}$$

$$P = \text{wetted perimeter (in.)}$$

The number of equivalent holes is obtained from:

$$N = \text{number of holes} = \frac{4A}{\pi (D_e)^2}$$

Loss coefficients are calculated for orifices and impedance rings such that:

$$\Delta P = CL \frac{G^2 v}{2g}$$

where

$$\Delta P = \text{pressure loss across orifice (psi)}$$

$$CL = \text{loss coefficient (dimensionless)}$$

$$G = \text{mass flow rate downstream of the orifice } \left(\frac{\text{lb}}{\text{sec in}^2} \right)$$

$$v = \text{specific volume of coolant } \left(\frac{\text{in}^3}{\text{lb}} \right)$$

$$g = \text{gravitational constant } \left(\frac{\text{in}}{\text{sec}^2} \right)$$

The heat flux into an equivalent channel is calculated and referenced to a heat flux table by use of a power factor, F , such that:

$$q_i = F q_o$$

where,

$$q_i = \text{heat flux into the equivalent channels of the } i\text{th section} \\ \left(\frac{\text{BTU}}{\text{sec in}^2} \right)$$

$$q_o = \text{reference heat flux } \left(\frac{\text{BTU}}{\text{sec in}^2} \right)$$

When the coolant passage is an annulus, the average heat flux is specified by

$$q_i = \frac{q_{ia} + q_{ib}}{2}$$

The subscripts a and b refer to the inner wall and outer wall of the annulus respectively.

A heat flux ratio, R_q , is used to specify the heat flux at each wall.

$$R_q = \frac{q_{ia}}{q_{ib}}$$

$$q_{ia} = \frac{2 q_i}{(1 + 1/R_q)}$$

$$q_{ib} = \frac{2 q_i}{(1 + R_q)}$$

The heat flux tables referred to in Table IV are shown in Table V. Heat flux values are tabulated versus axial position in the reference channel. The heat flux into any channel is obtained by multiplying the reference heat flux by the given power

factor, F . Table V-1 has the axial variation shown in Figure 2. Table V-2 includes heat conducted across the core-lateral support interface and is only used in determining the heat flux into the inner lateral support coolant holes. Figure 4 shows the assumed conducted heat flux from the core as a function of axial position. The flow conditions in the NERVA B-1 reactor with the redesigned reflector and lateral support is shown in Figure 5.

At this time, the results of the study of the temperature distribution in the lateral support should be considered approximate values. Initially, it was assumed that all of the heat generated in the graphite felt and the outer portion of the lateral support would be transferred to the annulus and that the heat generated in the inner portion plus the heat from the core would be transferred to the inner coolant holes. Figure 6 gives the resulting axial temperature distributions for several locations in the lateral support. The assumed adiabatic line has proven to be a good approximation in the region near the center of the core where the internal heat generation is highest. However, toward the exit end of the core where the heat generation is low, a considerable amount of heat from the hot core is conducted to the outer surface of the lateral support. Therefore, further iterative analyses are required to fully define the temperatures and fluid flow distributions in the lateral support area. The refinement of the calculations in the lateral support area should have little effect on the other reflector areas.

Figures 7 through 9 show the axial wall temperature distribution of the coolant channels shown in the diagram Figure 3. Selected hot spot temperatures in the reflector are presented in Figure 10.

The reactor station as plotted on the axis represents the distance from the reactor core face in inches.

3.2 NERVA B-2 REFLECTOR AND LATERAL SUPPORT

The reflector flow systems of the NERVA B-1 and the NERVA B-2 are similar except for the NERVA B-2 graphite reflector assembly. The graphite reflector assembly is made up of essentially three layers as shown in Figure 11. Adjacent to the core is a 1/8 inch thick layer of pyrolytic graphite tiles approximately 3 inches square. These tiles are pinned to longitudinal strips of 1/4 inch thick graphite. Each graphite strip is positioned by 8 graphite plungers and steel springs which keep the tiles in contact with the modules.

The plungers project through holes in the third concentric layer which consists of a nominal 1 7/8 inch thick graphite cylinder. Threaded graphite plugs retain the springs within the cylinder walls. Holes in the plugs allow propellant to flow over the springs and to leak past the plungers, through the annulus and into the nozzle chamber.

The redesigned reflector flow system (excluding the lateral support system) as described for the NERVA B-1 in 3.1 was used for the NERVA B-2 analysis.

Table I summarizes the flow channel information for the NERVA B-1 as reported in WANL-TNR-004. Table VI summarizes the flow channel information for the NERVA B-2. Table VII summarizes the materials comparison of the cross sectional area of the reflector considered in Phase I, WANL-TNR-004 and the NERVA B-2 reflector design reported herein.

The computer model of the NERVA B-2 reflector for analysis with MUCAP was similar to that described in 3.1 for the NERVA B-1. Table VIII summarizes the computer model assumed for the design of the B-2 reflector.

The heat flux table referred to in Table VIII is shown in Table V. Heat flux values are tabulated versus axial position in the reference channel. The heat flux into any channel is obtained by multiplying the reference heat flux by the given power factor, F . Table VIII has the axial variation shown in Figure 2. The flow conditions in the NERVA B-2 reactor with the redesigned reflector and lateral support is shown in Figure 12.

Figures 13 through 15 show the axial wall temperature distribution of the coolant channels shown in the diagram Figure 11.

The reactor station as plotted on the axis represents the distance from the reactor core face in inches.

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4.0 REACTOR CORE

WANL-TNR-004 reported the results of the Phase I design activity on the NERVA cores. The preliminary design results reflected the need of channel coolant flow control to obtain a more uniform radial propellant exit temperature. Subsequent preliminary design information on the redistribution of the propellant flow in the core is summarized in this report.

The B-1 and B-2 type cores were evaluated on the basis of 70 lb/sec flow, 550 psia exit pressure, and 4090°R uniform exit propellant temperature. Temperature distributions were determined for the NERVA B-1 and B-2 cores using the LASL axial power shape of an unshielded KIWI B-1A core. This power shape used is shown in Figure 16 and is identical with that used previously during Phase I.

The radial power shape for the B-1 is shown in Figure 17, and is also identical to that used in the previously reported analysis. The radial power shape used for the B-2 analysis is shown in Figure 18.

The MUCAP code was used to iteratively solve the heat transfer and flow equations to balance pressure drop and calculate coolant flows for the various core regions chosen. The orifice loss coefficient and the orifice pressure drop for each region was calculated to satisfy the uniform outlet temperature and total flow requirements.

4.1 NERVA B-1 CORE

Table IX summarizes the calculated operating parameters of the orificed B-1A core. The channels against which all others were orificed were those in Section 17. An orifice loss coefficient was assumed to be 1.4 for this section. The 1.4 loss coefficient

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is considered that occurring in an unorificed core coolant channel. These channels exhibited the highest pressure loss for the required operating conditions.

Figure 19 shows the radial variation in the maximum fuel, maximum wall, and coolant exit temperatures in the orificed core based on the LASL KIWI B-1A power curves. The unorificed core temperature maximum values are also given for comparison. The maximum material temperatures calculated with the WANL axial power curve were about 10°R lower.

Figure 20 shows the axial variation of maximum fuel, wall, and coolant exit temperatures for the central channel of the orificed core based on the LASL power curves. Although there is little difference in the maximum fuel temperature between the results from the LASL and WANL axial power shapes, the temperature distribution in the first 10 inches of the core is affected by the axial power shape in this part of the core.

Figure 21 shows the maximum fuel temperature distribution comparison of the two axial power shapes shown in Figure 17 considered in the first 10 inches. The LASL axial power curve results in larger axial temperature gradients than does the WANL curve.

The information in this summary report is reported as additional preliminary design information on the NERVA B-1 reactor. The final flight reactor core design selection will be dependent upon the results of the KIWI series reactor tests being conducted at Los Alamos Scientific Laboratories.

Table X summarizes the calculated operating parameters of the orificed B-2 core. The channels against which all others were orificed were those in Section 16. An orifice loss coefficient was assumed to be 1.4 for this section. The 1.4 loss coefficient is considered that occurring in an unorificed core coolant channel. These channels exhibited the highest pressure loss for the required operating conditions.

Figure 22 shows the radial variation in the maximum fuel, maximum wall, and coolant exit temperatures in the orificed core based on the LASL power curves. The unorificed core temperature maximum values are also given for comparison.

Figure 23 shows the axial variation of maximum fuel, wall, and coolant temperatures for the central channel of the orificed core based on the LASL power curves.

The information in this summary report is reported as additional preliminary design information on the NERVA B-2 reactor. The final flight reactor core design selection will be dependent upon the results of the KIWI series reactor tests being conducted at Los Alamos Scientific Laboratories.

4.2.1 PERTURBATIONS DUE TO CONTROL RODS

The fission density in the outer fuel elements is a function of angular displacement from the control rods. The variation of fission density is shown in Figure 24 (Ref LASL N-2-7292). The effect of this variation is shown in Figure 25 for both the unorificed and orificed core.

TABLE I
FLOW CHANNELS IN NERVA B-1 REFLECTOR (PHASE I)

Description	Number	Size (In.)	Location (In.)	Areg (In ²)
Slots in Lateral Support	42	0.0625 x 0.6875	36.36 O.D.	1.805
Inner Holes in Lateral Support	84	0.125 D.	36.5 D.	1.033
Outer Holes in Lateral Support	42	0.125 D.	37.0 D.	0.517
Holes in Beryllium Reflector	336	0.1875 D.	On diameters ranging from 41.375 to 46.875	9.275
Holes in Stainless Steel Tie Bolts	48	0.1875 D.		1.325
Inner Row	24		42.125 D.	
Outer Row	24		47.35 D.	
Holes in Control Drums	228	0.1875 D.	On diameters ranging from 0.0 to 2.375	6.294
Reflector-Lateral Support Annulus	1	0.125	40.0 I.D.	15.757
Reflector-Pressure Vessel Annulus	1	0.0625	49.25 I.D.	9.682
Aluminum Cylinder-Control Drum Annulus	12	0.0625	3.67 I.D.	5.572
Aluminum Cylinder-Reflector Annulus	12	0.040	3.92 I.D.	5.971
Control Strip-Control Drum Annulus	12	0.100	3.27 I.D.	4.281
Control Strip-Reflector Annulus	12	0.1125	3.57 I.D.	5.012

Total Flow Area = 66.524

TABLE II

FLOW CHANNELS IN NERVA B-1 REFLECTOR (SUBSEQUENT REDESIGN)

Description	Number	Size (In.)	Location (In.)	Area (In. ²)
Inner Holes in Lateral Support	168	0.15625 D.	84 on 36.25 D. 84 on 36.875 D.	3.221
Outer Holes in Lateral Support	42	0.15625 D.	37.0 D.	0.8052
Holes in Beryllium Reflector	384	0.1875 D		10.604
Inner Row	96		41.875 D.	
Second Row	96		43.125 D.	
Third Row	96		44.750 D.	
Outer Row	96		46.500 D.	
Holes in Stainless Steel Tie Bolts	24	0.1875 D.		0.662
Inner Row	12		42.25 D.	
Outer Row	12		46.75 D.	
Holes in Control Drum	84	0.1875 D.		2.320
Central Holes	12		Drum Center	
Outer Holes	72		2.0 D.	
Reflector-Lateral Support Annulus	1	0.125	40.0 I.D.	15.757
Reflector-Pressure Vessel Annulus	1	0.125	49.25 I.D.	19.390
Aluminum Cylinder-Control Drum Annulus	12	0.0625	3.67 I.D.	5.572
Aluminum Cylinder-Reflector Annulus	12	0.040	3.92 I.D.	5.971
*Control Strip-Control Drum Annulus	12	0.125	3.195 I.D.	6.139
*Control Strip-Reflector Annulus	12	0.125	3.545 I.D.	6.811

Total Flow Area = 77.25

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TABLE III

NERVA B-1 REFLECTOR MATERIAL COMPARISON

Material	Phase I Design		Subsequent Redesign	
	Description*	Area (In ²)	Description*	Area (In ²)
Graphite Felt in Lateral Support Density 13 lb/ft ³	42 pcs -	21.0	42 pcs - 2 in x 0.25 in	21.0
Pyrolitic Graphite Tiles	O.D. = 35.75 in I.D. = 35.5 in	14.0	O.D. = 35.75 in I.D. = 35.5 in	14.0
Graphite in Lateral Support	O.D. = 39.88 in I.D. = 35.75 in	221.0	O.D. = 39.88 in I.D. = 35.75 in	218.50
Stainless Steel Barrel	O.D. = 40.00 in I.D. = 39.88 in	77.53	O.D. = 40.00 in I.D. = 39.88 in	7.53
Stainless Steel Tie Bolts	48 pcs - O.D. = 0.5 in I.D. = 0.25 in	7.07	24 pcs - O.D. = 0.5 in I.D. = 0.25 in	3.53
Aluminum Control Drum	12 pcs - O.D. = 3.925 in I.D. = 3.80 in	10.38	12 pcs - O.D. = 3.925 in I.D. = 3.80 in	10.38
Borated Aluminum Control Strips	12 pcs - 4 in x 0.05 in	2.40	12 pcs - 4 in x 0.05 in	2.40
Beryllium Control Drums	12 pcs - O.D. = 4.0 in	110.98	12 pcs - O.D. = 4.0 in	111.30

* The dimensions shown refer to envelope dimensions and not material cross sectional area dimensions.

Table III (Cont'd)

NERVA B-1 REFLECTOR MATERIAL COMPARISON

Material	Phase I Design		Subsequent Redesign	
	Description*	Area (in ²)	Description*	Area (in ²)
Beryllium Reflector	O.D. = 49.25 in I.D. = 40.25 in	455.80	O.D. = 49.25 in I.D. = 40.25 in	462.77
Aluminum Pressure Vessel	O.D. = 51.625 in I.D. = 49.375 in	178.50	O.D. = 51.75 in I.D. = 49.5 in	178.92
Total Material		1028.66		1030.33
Flow Channel Void		66.52		77.25
Void Around Bolts		8.40		4.20
Void in Lateral Support		0.00		1.81
Void for Be Shims		0.00		0.00

TABLE IV
COMPUTER MODEL OF NERVA B-1 REDESIGNED REFLECTOR

Total Flow = 74.6 lb/sec	Hydrogen Inlet Temperature = 73.0 °R	Inlet Pressure = 684.4 PSIA
Total Power = 18.5 MW	Hydrogen Exit Temperature = 128.0 °R	Exit Pressure = 674.0 PSIA

Section	Description	Flow Area (In ²)	Equivalent Diameter D _e (In)	No. of Channels N	Heat* Flux Table	Power Factor F	Heat Flux Ratio R _q	Loss Coefficient CL
0	Computer Reference Channel	0.0	0.20	0.0	1 & 2	1.0		
1	Beryllium - Graphite Annulus							
	1a - Graphite	15.757	0.25	321.0	1	1.218	4.142	
	1b - Beryllium							
2	Beryllium - P. V. Annulus							
	2a - Beryllium	19.390	0.25	395.0	1	.435	.503	20 at
	2b - Pressure Vessel							STA.
								+ 6.25
3	Inner Tie Bolts	0.331	0.1875	12.0	1	2.428		
4	Outer Tie Bolts	0.331	0.1875	12.0	1	1.178		
5	Inner Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.732		
6	Second Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.732		
7	Third Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.731		

* See Table V.

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Table IV (Cont'd)

COMPUTER MODEL OF NERVA B-1 REDESIGNED REFLECTOR

Total Flow = 74.6 lb/sec
Total Power = 18.5 MW

Hydrogen Inlet Temperature = 73.0 °R
Hydrogen Exit Temperature = 128.0 °R

Inlet Pressure = 684.4 PSIA
Exit Pressure = 674.0 PSIA

Section	Description	Flow Area (In ²)	Equivalent Diameter D _e (In)	No. of Channels N	Heat Flux Table	Power Factor F	Heat Flux Ratio R _q	Loss Coefficient CL
8	Outer Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.727		
9	Holes in Control Drum	2.320	0.1875	84.0	1	.733		
10	228° Aluminum Cylinder-Control Drum Annulus 10a - Control Drum 10b - Aluminum Cylinder	5.572	0.1157	530.0	1	.20	5.274	9.4 at STA. + 0.25
11	Aluminum Cylinder-Beryllium Reflector Annulus 11a - Aluminum 11b - Beryllium	5.971	0.0800	1188.0	1	.1516	.2095	7.7 at STA. + 0.25
12	Control Strip Annuli 12a - Control Strip 12b - Aluminum & Beryllium	12.95	0.2077	318.0	1	.828	1.0 × 10 ⁶	
13	Holes in Outer Portion of Graphite Lateral Support	0.8052	0.15625	42.0	1	1.971		
14	Holes in Inner Portion of Graphite Lateral Support	3.221	0.15625	168.0	2	1.0		

* See Table V.

Total Flow Area = 77.25

TABLE V
REFERENCE HEAT FLUX TABLES

Reactor Station (Distance from Core Inlet Face-Inches)	Reference Heat Flux (BTU/SEC IN ²)	
	Table V-1	Table V-2
+ 0.25	0.0855	0.176
+ 5.0	0.181	0.503
+ 10.0	0.267	0.808
+ 15.0	0.334	1.069
+ 20.0	0.382	1.270
+ 25.25	0.398	1.381
+ 30.0	0.378	1.386
+ 35.0	0.330	1.322
+ 40.0	0.261	1.198
+ 45.0	0.171	1.019
+ 50.0	0.072	0.810
+ 52.25	0.0199	0.714

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TABLE VI
 FLOW CHANNELS IN NERVA B-2 REFLECTOR

Description	Number	Size (In)	Location (In)	Area (In)
Holes in Lateral Support	108	0.1875 D.		2.982
Holes in Beryllium Reflector	384	0.1875 D.		10.604
Inner Row	96		41.875 D.	
Second Row	96		43.125 D.	
Third Row	96		44.750 D.	
Outer Row	96		46.500 D.	
Holes in Stainless Steel Tie Bolts	24	0.1875 D.		0.662
Inner Row	12		42.25 D.	
Outer Row	12		46.75 D.	
Holes in Control Drum	84	0.1875 D.		2.320
Central Holes	12		Drum Center	
Outer Holes	72		2.0 D.	
Reflector - Lateral Support Annulus	1	0.125	40.0 I.D.	15.757
Reflector - Pressure Vessel Annulus	1	0.125	49.25 I.D.	19.390
Aluminum Cylinder - Control Drum Annulus	12	0.0625	3.67 I.D.	5.572
Aluminum Cylinder - Reflector Annulus	12	0.040	3.92 I.D.	5.971
Control Strip - Control Drum Annulus	12	0.125	3.195 I.D.	6.139
Control Strip - Reflector Annulus	12	0.125	3.545 I.D.	6.811

Total Flow Area = 76.21

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TABLE VII
NERVA B-1 AND NERVA B-2 REFLECTOR MATERIAL COMPARISON

Material	Phase I		NERVA B-2	
	Description*	Area (In ²)	Description*	Area (In ²)
Graphite Felt in Lateral Support Density 13 lb/ft ³	42 pcs -	21.0		
Pyrolitic Graphite Tiles	O.D. = 35.75 in I.D. = 35.5 in	14.0	O.D. = 35.75 in I.D. = 35.5 in	14.0
			O.D. = 36.00 in I.D. = 35.50 in	14.09
Graphite in Lateral Support	O.D. = 39.88 in I.D. = 35.75 in	221.0	O.D. = 39.88 in I.D. = 36.13 in	223.87
Stainless Steel Barrel	O.D. = 40.00 in I.D. = 39.88 in	77.53	O.D. = 40.00 in I.D. = 39.88 in	77.53
Stainless Steel Tie Bolts	48 pcs - O.D. = 0.5 in I.D. = 0.25 in	7.07	24 pcs - O.D. = 0.5 in I.D. = 0.25 in	3.53
Aluminum Control Drum Cylinders	12 pcs - O.D. = 3.925 in I.D. = 3.80 in	10.38	12 pcs - O.D. = 3.925 in I.D. = 3.80 in	10.38
Borated Aluminum Control Strips	12 pcs - 4 in x 0.05 in	2.40	12 pcs - 4 in x 0.05 in	2.40

* The dimensions shown refer to envelope dimensions and not material cross sectional area dimensions.

Table VII (Cont'd)

NERVA B-1 AND NERVA B-2 REFLECTOR MATERIAL COMPARISON

Material	Phase I		NERVA B-2	
	Description*	Area (In ²)	Description*	Area (In ²)
Beryllium Control Drums	12 pcs - O.D. = 4.0 in	110.98	12 pcs - O.D. = 4.0 in	111.30
Beryllium Reflector	O.D. = 49.25 in I.D. = 40.25 in	455.80	O.D. = 49.25 in I.D. = 40.25 in	462.77
Aluminum Pressure Vessel	O.D. = 51.625 in I.D. = 49.375 in	178.50	O.D. = 51.75 in I.D. = 49.5 in	178.92
Total Material		1028.66		1030.33
Flow Channel Void		66.52		76.21
Void Around Bolts		8.40		4.20
Void in Lateral Support		0.00		1.81
Void for Be Shims		0.00		0.00

* The dimensions shown refer to envelope dimensions and not material cross sectional area dimensions.

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TABLE VIII
COMPUTER MODEL OF NERVA B-2 REFLECTOR

Total Flow = 74.6 lb/sec Hydrogen Inlet Temperature = 73.0 °R Inlet Pressure = 684.4 PSIA
Total Power = 18.5 MW Hydrogen Exit Temperature = 128.0 °R Exit Pressure = 674.0 PSIA

Section	Description	Flow Area (In ²)	Equivalent Diameter D _e (In)	No. of Channels N	Heat Flux Table	Power Factor F	Heat Flux Ratio R _q	Loss Coefficient CL
0	Computer Reference Channel	0.0	0.20	0.0	1	1.0	4.	
1	Beryllium-Graphite Annulus							
	1a - Graphite	15.757	0.25	321.0	1	1.218	4.142	
	1b - Beryllium							
2	Beryllium - P. V. Annulus							
	2a - Beryllium	19.390	0.25	395.0	1	.435	.503	20 at STA.
	2b - Pressure Vessel							+ 6.25
3	Inner Tie Bolts	0.331	0.1875	12.0	1	2.428		
4	Outer Tie Bolts	0.331	0.1875	12.0	1	1.178		
5	Inner Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.732		
6	Second Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.732		
7	Third Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.731

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Table VIII (Cont'd)

COMPUTER MODEL OF NERVA B-2 REFLECTOR

Total Flow = 74.6 lb/sec		Hydrogen Inlet Temperature = 73.0 °R		Inlet Pressure = 684.4 PSIA				
Total Power = 18.5 MW		Hydrogen Exit Temperature = 128.0 °R		Exit Pressure = 674.0 PSIA				
Section	Description	Flow Area (In ²)	Equivalent Diameter D _e (In)	No. of Channels N	Heat Flux Table	Power Factor F	Heat Flux Ratio R _q	Loss Coefficient CL
8	Outer Row of Holes in Beryllium Reflector	2.651	0.1875	96.0	1	.727		
9	Holes in Control Drum	2.320	0.1875	84.0	1	.733		
10	228° Aluminum Cylinder-Control Drum Annulus	5.572	0.1157	530.0	1	.20	5.274	9.4 at STA. + 0.25
	10 a - Control Drum							
	10 b - Aluminum Cylinder							
11	Aluminum Cylinder - Beryllium Reflector Annulus	5.971	0.0800	1188.0	1	.1516	.2095	7.7 at STA. + 0.25
	11a - Aluminum							
	11b - Beryllium							
12	Control Strip Annuli							
	12a - Control Strip	12.95	0.2077	318.0	1	.828	1.0 x 10 ⁶	
	12b - Aluminum & Beryllium							
13	Holes in Graphite Lateral Support	2.982	0.1875	.08	1	2.658		

TABLE IX
SUMMARY OF ORIFICED B-1A CORE

Total Flow = 70 lb/sec
Total Power = 1100 MW

Hydrogen Inlet Temperature = 130 °R
Hydrogen Exit Temperature = 4090 °R

Inlet Pressure = 674 PSIA
Exit Pressure = 550 PSIA

Region	Range I.D. - O.D	Radial Power Factor	Section	Channel Diameter (In)	Number of Holes	Orifice Pressure Loss	Orifice Loss Coeff.	Flow/ch lb/sec
1	0. - 1.25	1.08	1	.156	49	12.1	24.1	.0093
2	1.25 - 3.94	1.07	2	.156	378	14.1	28.5	.0092
3	3.94 - 7.0	1.03	3	.156	882	21.4	47.0	.0088
4	7.0 - 9.13	.981	4	.154	882	21.7	48.3	.0086
5	9.13 - 10.51	.957	5	.152	756	18.1	39.3	.0085
6	10.51 - 13.0	.961	6	.150	1596	8.9	17.8	.0086
7	13.0 - 15.7	1.043	7	.152	672	1.6	2.9	.0092
			8	.154	228	10.3	20.3	.0090
			9	.156	306	18.6	39.6	.0090
			10	.158	180	26.4	60.8	.0089
			11	.160	204	33.7	83.8	.0088
			12	.162	198	40.6	108.9	.0086
			13	.164	132	46.9	136.0	.0085
			14	.166	90	52.8	165.3	.0084
			15	.168	84	58.3	197.2	.0083
			16	.170	48	63.4	231.6	.0081
8	15.7 - 17.7	.957	17	.148	48	.8	1.4	.0087
			18	.150	120	9.7	19.5	.0086
			19	.152	168	18.1	39.3	.0085
			20	.154	144	26.0	60.8	.0083
			21	.156	120	33.3	84.4	.0082
			22	.158	102	40.2	109.8	.0081
			23	.160	132	46.6	137.4	.0080
			24	.162	162	52.9	167.4	.0079
			25	.164	180	58.0	199.7	.0078
			26	.166	120	63.1	234.6	.0078
			27	.168	96	67.8	272.3	.0076
			28	.170	36	72.1	313.2	.0075

TABLE X
SUMMARY OF ORIFICED B-2 CORE

Total Flow 70 lb/sec Total Power 1100 MW		Hydrogen Inlet Temperature 130°R Hydrogen Exit Temperature 4090°R			Inlet Pressure PSIA Exit Pressure 550 PSIA		
Section	Range I.D. - O.D.	Radial Power Factor	Diameter	No. of Channels	Orifice Pressure Loss	Orifice Loss Coefficient	flow/ch lb/sec
1	0 - 3.0	.993	.156	247	0.74	1.40	.00955
2	3.0 - 5.0	.971	.156	432	5.00	9.78	.00936
3	5.0 - 7.2	.943	.156	672	11.69	24.51	.00904
4	6.5 - 9.1	.910	.154	840	13.29	28.65	.00869
5	8.8 - 10.4	.885	.152	756	14.06	30.92	.00838
6	10.0 - 12.9	.885	.150	1596	10.20	21.78	.00829
7	12.2 - 14.7	.930	.152	672	11.86	25.48	.00848
8	13.1 - 14.1	.947	.154	270	17.48	39.44	.00850
9	13.7 - 14.4	.958	.156	264	15.32	33.38	.00887
10	14.3 - 14.6	.970	.158	180	19.78	44.80	.00893
11	14.6 - 14.9	.982	.160	204	21.62	49.45	.00911
12	14.9 - 15.2	.995	.162	198	22.56	51.63	.00934
13	15.0 - 15.3	1.008	.164	132	27.54	66.08	.00934
14	15.1 - 15.4	1.018	.166	90	30.78	76.04	.00943
15	15.2 - 15.5	1.030	.168	84	34.02	86.64	.00952
16	15.4 - 15.7	1.040	.170	48	37.25	97.92	.00959

Table X (Cont'd)

SUMMARY OF ORIFICED B-2 CORE

Total Flow 70 lb/sec Total Power 1100 MW		Hydrogen Inlet Temperature 130°R Hydrogen Exit Temperature 4090°R			Inlet Pressure PSIA Exit Pressure 550 PSIA		
Section	Range I.D. - O.D.	Radial Power Factor	Diameter	No. of Channels	Orifice Pressure Loss	Orifice Loss Coefficient	flow/ch lb/sec
17	15.4 - 15.6	.750	.148	12	41.23	128.90	.00667
18	15.3 - 15.8	.770	.150	54	43.34	137.88	.00679
19	15.5 - 15.8	.790	.152	162	43.51	137.12	.00700
20	15.8 - 16.0	.800	.154	204	45.81	147.51	.00711
21	16.0 - 16.2	.820	.156	132	49.02	163.66	.00717
22	16.2 - 16.5	.840	.158	24	47.92	155.62	.00745
23	16.5 - 16.8	.900	.161	216	39.50	111.98	.00828
24	16.8 - 17.1	.930	.163	324	37.87	103.95	.00863
25	17.1 - 17.3	.960	.165	216	33.98	87.82	.00911

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FIGURE 2 AXIAL VARIATION OF INTERNAL HEAT GENERATION IN THE NERVA B-1
REFLECTOR AND LATERAL SUPPORT

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FIGURE 3
 REDESIGNED NERVA B-1 REFLECTOR AND LATERAL SUPPORT

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FIGURE 4 HEAT FLUX ACROSS CORE-LATERAL SUPPORT INTERFACE

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FIGURE 5

Flow Conditions in the Nerva B-1 Reactor with Redesigned Reflector and Lateral Support and Orificed Core Collant Channels

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FIGURE 8—AXIAL WALL TEMPERATURE VARIATION FOR REFLECTOR TIE BOLT COOLANT CHANNELS

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FIGURE 11
NERVA B-2 REFLECTOR AND LATERAL SUPPORT

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FIGURE 12

FLOW AND TEMPERATURE
DISTRIBUTION IN REDESIGNED
REFLECTOR

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FIGURE 13 WALL TEMPERATURE DISTRIBUTION IN REDESIGNED B-2 REFLECTOR FOR SECTIONS 1 THROUGH 8

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FIGURE 14 WALL TEMPERATURE DISTRIBUTION IN REDESIGNED B-2 REFLECTOR FOR
SECTIONS 9 THROUGH 13

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FIGURE 16 AXIAL POWER VARIATION IN THE B-1A CORE

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FIGURE 17 RADIAL POWER DISTRIBUTION FOR THE B-1A CORE

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FIGURE 21 COMPARISON OF AXIAL TEMPERATURE DISTRIBUTIONS IN THE B-1A CORE WITH LASL AND WANL AXIAL POWER SHAPES

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FIGURE 23

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PERTURBATION OF FISSION DENSITY IN OUTER FUEL ELEMENTS IN KIWI B-2A

FIGURE 24

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