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**Westinghouse
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WANL-TME-2707
SEPTEMBER 1970

DATA ITEM S-54

**NSS RADIAL DIMENSION
OPTIMIZATION STUDY (U)**

TRADE STUDY NO. 776

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TRADE STUDY NO. 776

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ABSTRACT

A trade study of parameters affecting the outside radial dimension of the reflector assembly, a component of the NERVA Nuclear Subsystem (NSS), is presented. The purpose of this study is to provide justification of the parameters affecting the radial dimension and to determine the most logical and reasonable combination of component radial dimensions to minimize the reflector assembly outside dimension.

The evaluation and selection of the radial dimension is based upon a computerized design technique. This design technique was developed with the objective of maximum utilization of previous design studies and independent engineering studies of individual components while also accounting for the dependence between the various design parameters.

The functional and technical requirements are identified by the Systems Engineering Component Specifications EC-677559 (Reflector Assembly), EC-677564 (Core Periphery), and EC-677566 (Core). Additional requirements are specified by SNPO-C Change Order 70-8 which are given in the introduction section of this study.

The base case configuration evaluated in this study is similar to the aluminum structure design which was selected in the NERVA Reflector Assembly Design Concepts Trade Study, No. 763, February 1970.

The optimized, or minimum, reflector assembly outside radial dimension recommended as a result of this study is 54.00 inches. The factors leading to this selection are described in this report. Presentations of this trade study were made to SNPO and ANSC at WANL and SNPO-Germantown on June 3, 1970, and June 11, 1970, respectively (Reference A-1 and A-2).

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1.0 INTRODUCTION

The purpose of this study is to provide justification of the overall radial dimension of the Nuclear Subsystem (NSS), which consists of the components shown in Figure 1.0-1. Parameters which are fixed or varied within this study commence with the core and terminate with the inclusion of the annular flow channel between the reflector and the pressure vessel.

The reflector concept which is analyzed in this study is similar to the aluminum structure design selected in the NERVA Reflector Assembly Design Concepts Trade Study No. 763 (WANL-TME-2673, February 1970). The concept has been modified in response to SNPO-C Change Order 70-8, Item 23, which is as follows:

"The Al-Be reflector shall be used in the NSS in place of the all Be reflector. However, aluminum alloys other than 2219 shall be used. As stated in T. D. 70-26, the control drum span should be no greater than \$4.50 and should include a restart capability after the one-dollar corrosion loss. In addition, the reflector design should be based on a shim capability of ± 1.50 and a maximum fuel loading of 630 mg (for graphite fuel). The minimum diameter reflector should be designed consistent with the foregoing constraints and minimizing all contributing parameters, including the following:

- a. Lateral support spacing
- b. Al cylinder thickness
- c. Al web radial thickness
- d. Beryllium thickness."

The aluminum structure material (6061-T61) was selected by and documented in a previous trade study (Reference 1.0-1).

This study also will document the response to Change Order 70-8, Item 21 to the extent required to optimize the periphery design radial dimension. Item 21 stated the following:

Figure 1.0-1. Relative Location of NSS Components Affecting Radial Dimension

"The thickness allowance for the NSS periphery design shall be held to a minimum and shall be justified in terms of periphery design requirements. Updated program plans and logic reflecting emphasis on the development of core periphery designs and materials (including non-corrodible designs) shall be prepared and submitted by April 15, 1970."

Design variations of the lateral support system and investigation of its compatibility with the hard vacuum environment (10^{-9} torr) will be performed and documented in a subsequent study.

The remainder of this report is organized into three chapters. Chapter 2 deals with the approach utilized to optimize the reflector assembly O. D. It consists of four sections. The first of these sections defines the general approach. The second section describes the components included in this optimization study, their geometric relationships, design requirements, and materials. The third section defines fixed and variable parameters of each component and specifies the range and limit of the parameters. The fourth section presents the mathematical techniques utilized in optimizing the parameters. This consists of a brief description of the Radial Sizing Program (RSP). Chapter 3 indicates the results of the parametric study by showing how the various design parameters affect the reflector O. D. It also shows the effect these parameters have on certain other design parameters. Chapter 4 contains the recommendations derived as a result of this study.

2.0 APPROACH UTILIZED TO OPTIMIZE RADIAL DIMENSION

Determining the optimum radial dimensions of a system as complex as the NERVA nuclear subsystem involves considering a large number of independent and dependent design parameters. Design parameters from the core, core periphery, and reflector assembly areas affect each other because of the multiple nuclear, thermal, and structural requirements and, as a result, affect the O. D. of the NSS. A computerized design technique was developed to provide an optimum set of radial dimensions in a reasonable length of time and at a reasonable cost. This design technique was developed with the objective of making maximum use of previous design studies and independent engineering discipline studies of individual components while also accounting for the dependence between the various design parameters.

Figure 2.0-1 is a block diagram of the radial sizing design process which indicates the dependence of the design parameters in the various component areas. The input variables (independent parameters) are located on the left side of the diagram. Internal and output variables (dependent parameters) are shown between blocks and flowing (around) to adjacent blocks respectively. Each block represents the pertinent design process for the component named and the blocks are connected by a flow of design information which other blocks require. Some of the output variables flow in a forward direction while others, feedback variables, flow in the reverse direction. The loops resulting from this forward and backward flow of design information make it necessary to execute the design process numerous times so that the feedback variables are truly representative of the particular design that is developing. These iterations are extremely time consuming and costly when the design process is executed manually, but are important in determining the minimum component radial dimensions which permit the various design requirements to be satisfied. These iterations are handled easily by constructing a mathematical model of the design process and executing the model on a digital computer. To construct this mathematical model, each Design Engineering discipline developed functional relationships related to sizing each component to meet its design requirements or in support of another functional relationship. The functional relationships are as simple as possible while still providing a reasonably

Figure 2.0-1. Block Diagram of Radial Sizing Design Process Logic

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representative effect of one variable on another. Typically, these relationships are either the governing physics equations or the tabulated results of a more detailed supporting study with interpolation and extrapolation formulae.

The objective of the computerized design program is to determine the effect that the input design variables have on the NSS O. D. and internal variables so that the values of the input variables that give the minimum NSS O. D. can be identified and to establish, when an input variable is at its limit, the cost (in terms of O. D.) of limiting the input variables. Section 2.2 of this report discusses the design parameters considered in this computerized design program along with the design parameters that were fixed. Section 2.3 describes the logic in the computerized design program.

The base case configuration layout, Figure 2.0-2 (Drawing No. 982D265) was made to establish a common base point from which to conduct this study.

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2-4

GRAPHITE CORE (REP)
94 SO DRUM SPIN
852 PSI RADIAL AP
20 LATERAL SUPPORT
2 ROWS 50° SEAL SEGMENTS

STUDY LAYOUT

NP 1
L. RAMPART & 100 70
D. RAMPART

NSS RADIAL COMPONENTS
ALUMINUM STRUCTURE
STUDY LAYOUT OF - (U)

982D265

W
A

1
4 10000 A
CER

CPD
S. W. P. 1/10/70

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Figure 2.0-2. Base Case Configuration

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2.1 COMPONENTS

2.1.1 Core

2.1.1.1 Introduction

The core is a prime consideration in determining the overall radial dimensions of the NSS. The core consists of an arrangement of fueled element clusters (see Figure 2.1.2-2). The requirement for the number and size of fuel elements making up this core is discussed in Section 2.1.1.3.

2.1.1.2 Requirements

The core shall consist of fueled elements and support elements which meet the requirements in Specification EC-677566 which forms a part of CP-677555 NERVA NSS.

An important requirement is that the thermal expansion of the matrices is controlled to not exceed 1.802 percent of the as-assembled core dimensions to be compatible with mating core and component capabilities.

2.1.1.3 General Geometric Relationship

Both the graphite and composite type core are considered for their effects upon this study. Prime factors of the core which contribute to sizing of the radial dimensions are the core expansion, mass, and nuclear effects. This study utilizes the higher expansion of the composite fuel to establish the lateral spacing which permits utilization of the graphite core within the same envelope without requiring physical change of the aluminum structure inside diameter. Weights of the two core types are utilized for determination of the lateral support system spring sizing and for lateral load capability evaluation. The nuclear properties of the cores pertain most directly to the beryllium reflector thickness and the control drum diameter requirements. Various fueled element geometries were considered and the standard geometry high expansion graphite fueled element and the standard geometry composite fueled element were the concepts selected and recommended for continued development (Reference 2.1.1-1).

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(C-RD) The nominal design parameters pertinent to both the standard geometry graphite fueled element (Reference Drawing Number 947C827) and standard geometry composite fueled element (Reference Drawing Number 947C829) are:

- a) 0.753 - inch across flats dimension
- b) 19 flow channels
- c) 0.102 - inch reamed channel diameter
- d) 52 - inch length.

(U) The general array of the core fueled and central elements is included in Figure 2.1.2-2 of the periphery component section. The way in which this particular arrangement was selected is outlined below. Different core diameters were considered in the Trade Study 769 and the number of elements selected as most advantageous was:

1878 Fueled Elements

349 Unfueled Centrals.

(U) Prime factors leading to the selection of this core diameter were:

- a) If fewer elements were used (smaller core):
 - 1) lower core weight
 - 2) higher loadings affect properties adversely
 - 3) higher matrix temperature and lower temperature margin
 - 4) fewer channels result in higher core Δp
 - 5) higher thermal stress due to higher internal heat generation.
- b) If more elements were used (larger core) then the inverse of the above five factors would apply with a resultant increase in element reliability.

(U) The equivalent core radius for this array based on the nominal size and quantities of fueled and central elements for the fueled region of the core is 18.66 inches at room temperature.

2.1.1.4 Materials (U)

(C-RD) The graphite fueled element matrix is high expansion graphite (AXF) with a 65/35 weight percent NbC composite tip at the aft end. The flow channels are coated first with 41 grams of Nb deposited by the methane process followed by 60 grams of Zr deposited by the diffusion process. External surfaces are coated first with 0.0011 inch average thickness of NbC extending from Station 0 to 52 followed by 0.001 inch average thickness of ZrC extending from Station 40 to 52.

(U) This coating was selected since:

- a) more Nb gives a better CTE match with the matrix but increased neutron absorption. Nb base coat gives higher eutectic melt point for coating in contact with uranium from the beads.
- b) more Zr provides adequate CTE match and coating adherence along with increased reactivity to allow reduction in reflector weight.

(C-RD) The composite fueled element matrix is 30 v/o UC-ZrC-C with no tip at the aft end. The flow channels of each element are coated with a total of 90 grams of Zr deposited by the GEM process. The external surface at the aft end is coated with 1 gram of GEM Zr.

(U) Some restraints imposed on the core materials selected include:

- a) The core reactivity change available through shimming be \$1.5.
- b) The loading of high expansion graphite elements shall not exceed 630 mg/cc or uranium. The 30 v/o composite element loading shall not exceed 700 mg/cc of uranium.

(U) The element matrix using high expansion graphite is lighter than the composite element. However, the composite element has better corrosion resistance, but as indicated by preliminary calculations, appears to have a greater likelihood of structural failure. The core weights calculated for graphite matrix elements and for 30 v/o composite elements are 4875 and 6600 pounds, respectively.

2.1.2 Periphery (U)

2.1.2.1 Introduction (U)

(U) The core periphery provides a mechanical and thermal transition between the fuel boundary and reflector system. The design objectives are to be accomplished placing increased emphasis on the corrosion resistant periphery concept.

2.1.2.2 Requirements (U)

(U) The core periphery must comply with the requirements in Specification No. EC-677555, which forms a part of CP-677555, NERVA NSS. The key items that limit the size of the core periphery envelope include the radial outward (or inward) heat flux from the fuel boundary, the insulation conductivity, the core by-pass flow magnitude (affects the fuel exit gas temperature requirements), and the material structural integrity of the radial flow barrier and filler strip.

(C-RD) The insulation and wrapper radial periphery thickness outward from the fuel boundary is established by considering minimizing the outward heat flux at the fuel boundary and minimizing the core by-pass flow considering a representative corrosion resistant insulating material. Reference 2.1.2.1 establishes the minimum thickness of the insulation envelope as approximately .260 inch (allowing up to .010 inch of composite to provide the equivalent insulating effect of the ZrC protective strip) using 75 w/o ZrO_2 -25 v/o ZrC composite as the representative insulating material. Providing room for a wrapper and slip planes outward of the insulation resulted in selecting a minimum insulation plus wrapper combined thickness of .275 inch. Depending on fuel outward flux capabilities, the approximate range of insulator conductivities allowable for this combined thickness are indicated in Figure 2.1.2.1. The zero margin of safety (SNPO-C-1 definition) allowable fuel outward flux, based on current fuel property estimates, appears to be on the order of .7 and .5 (BTU/in²-sec) at Station 50 for graphite and composite fuels respectively (Reference 2.1.2.2). While the lack of detail material properties and a final design prevent an exact sizing of the minimum insulation plus wrapper thickness, it is felt that the .275 inch thickness is a reasonable minimum requirement.

(U) A minimum filler strip radial edge thickness of .087 is needed to prevent significant degradation of the edges during fabrication, handling and assembly based on past experience.

(CRD) 2.1.2.3 General Geometric Relationship (U)

(C-RD) The general configuration that is defined by the requirements is shown in Figure 2.1.2-2 and employs rigid corrosion resistant insulation. The periphery envelope includes as the representative insulating material candidate at this time, axial segments of 75 % ZrO_2 - 25 % ZrC composite material against the fuel boundary aft of Station 17. An axial pyrofoil wrapper acting as a forward end seal is placed between Station 4.5 and Station 17.0. A full length stainless wrapper with pyrofoil slip planes acts as the radial flow barrier outside the insulation and pyrofoil. Cooled filler strips outside of the metal wrapper round out the core periphery to a cylindrical shape to fit the lateral support seal segments.

2.1.2.4 Materials (U)

(U) Prime candidate materials under consideration for the insulation part of the design include ZrC , ZrC/ZrO_2 , ZrO_2 , ZrC Foam, and ThO_2 Coating on ZrC . An expanded survey and evaluation of additional corrosion resistant insulation materials is also underway. The present core periphery constraints require coolant bypass to limit the outside insulation temperature to $1500^{\circ}R$ to permit the use of a stainless steel wrapper for a radial flow barrier. Filler strips are made of Graphitite G.

INSULATOR THICKNESS (IN)

Figure 2.1.2-1. Approximate Heat Flux Variation at Sta. 50

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Figure 2.1.2-2. Periphery With Envelope for Combined Wrapper and Insulation

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2.1.3 Lateral Support

2.1.3.1 Introduction

The lateral support consists primarily of inner and outer seal ring segments, plungers and radial compression springs (the springs will be elaborated on in Section 2.1.4). The physical relationship of these parts is shown in Figure 2.1.3-1. Nine inner and outer segments and 36 plungers and springs comprise an axial row of the lateral support. The lateral support consists of a total of 21 axial rows.

The radial gap between the core periphery and the insulation on the inside diameter of the reflector structure has been fixed for purposes of this study. The gap is based upon the expansion of the composite core (Reference 2.1.3-1) and the contraction of the aluminum reflector structure. Sizing of the gap is based upon equations which take into consideration actual tolerances expected on the manufactured components as well as the thermal effects (Reference 2.1.3-2). The seal interface angle θ has been established at 30 degrees because this angle permits operation at a higher coefficient of friction when compared to the 45 degree seal and additionally decreases plunger stress and spring deflections.

2.1.3.2 Requirements

The lateral support must comply with the requirements specified in reflector assembly specification No. EC-677559, which forms a part of CP-677555, NERVA NSS. The primary requirement of the lateral support is to laterally restrain relative motion of the core and to center it with respect to the reflector structure and to provide a mechanical bundling force upon the core elements. The lateral support shall also be capable of accommodating the relative radial thermal motion of the core and reflector structure during all phases of operation as discussed in the preceding paragraphs.

The basic dynamic parameter is the breakaway G level, G_{BA} , which is the input G level at which any relative motion occurs between the core assembly and the reflector. This parameter is computed analytically for an average coefficient of friction using the Structural Design computer program LATSUP and verified in static and dynamic partial length core tests to be independent of the input frequency.

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Figure 2.1.3-1. Lateral Support Configuration

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Another dynamic parameter governing the response is the parameter G_{IMP} which is the input G level which causes impact or the limit of relative motion. Both analysis and partial length core test results indicate that G_{IMP} is highly frequency dependent. At frequencies in excess of 2 times the undamped LSS natural frequency, the parameter G_{IMP} is approximately double the value of G_{BA} and the value of G_{IMP} increases with increasing frequency. Furthermore, as the input displacement decreases with the square of the frequency, being ± 24 mils for a $3G$ input at 35HZ for reference, it is apparent that higher possible G levels are not limiting at any frequency above 2 times the undamped natural frequency. Rather, a displacement limitation is a realistic limit above this frequency.

At frequencies below this limit (2 times the natural frequency of the LSS) the parameter G_{IMP} becomes closer to G_{BA} . Theoretical limits show that at the natural frequency $G_{IMP} = (4/\pi) G_{BA} \approx 1.3 G_{BA}$. Partial length core tests tend to indicate that this theoretical estimate of G_{IMP} is conservative and that the actual impact G level is twice the breakaway G level.

For dynamic considerations, a value of the parameter is selected so that:

- 1) No relative core reflector lateral motion occurs near the first mode (up to 20HZ) of dynamic magnification.
- 2) No large core reflector lateral motion occurs for frequencies above 20HZ .

The dynamic requirement considerations for the LSS are based on:

- 1) INT - 21, SATURN V Type, launch criteria.
- 2) SN stage space operations.
- 3) Sufficient mechanical bundling to insure a compact core.

The actual boost dynamic loads on the NSS will not be available until the S-038 report is completed for NSS/PDR. Until this analysis is completed, the only firm loads are those recommended from the 3 December 1968 meeting of the Environmental Loads Committee which are harmonic acceleration loads acting at the engine-stage interface:

$\pm 1.5 G$ from 1 to 34 HZ
 $\pm 2.0 G$ from 34 to 500 HZ .

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The lower frequency level of ± 1.5 G spans the range of the current LSS natural frequency of roughly 10 HZ.

Very little detailed dynamic analysis has been performed on current engine designs. Some overall dynamic analyses performed in 1968, using a hot-bleed engine design, indicated very low dynamic magnification throughout the lower frequencies. Some recent stage and engine modal analyses have indicated that there may be modal coupling between the stage and the engine, and possibly between the booster and the components. The current recommendation is that the LSS be designed for a 3G impact criterion based on an INT-21 launch criteria. Theoretical analyses and testing experience indicates that this goal can be met with a 2G breakaway requirement for an INT-21 launch.

Detailed NSS dynamic analyses of SN stage space operations will not be available until NSS/PDR. Indeed the turbopump and nozzle forcing functions used in these analyses are only in the preliminary stage of definition at ANSC. Therefore, the NSS space operation input spectrum used in this study should be considered as an educated estimate of the environment. The education is a result of detailed studies of response data, considering both the magnitude and the frequency of the respective responses, which was obtained from wide band instrumentation on the pressure vessel, nozzle, support plate and reflector during the previous reactor tests. A greater weighting was placed on A-6 data than on the previous reactor tests because its design at the pressure vessel interface more closely approximates the current R-1 design. Consideration was also given to the fact that certain ground test excitations, such as external acoustic forcing, will not be present in space. Based on these considerations, the NSS response spectrum shown in Figure 2.1.3-2 was generated. In order to satisfy dynamic considerations for an SN stage operation, a value of $G_{BA} = .75$ Gs (which is one-half of the 1.5 Gs acting at 35 HZ) is conservatively assumed as the dynamic requirement. This G_{BA} value corresponds to a G_{IMP} of 1.5 Gs which prevents impact at frequencies with amplitudes large enough to cause impact. This G_{BA} value is also sufficient to preclude any relative core/reflector motions near the LSS first natural frequency.

Figure 2.1.3-2. NSS Vibration Spectrum for Space Operation

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Experience in assembling reactors has shown that a minimum bundling pressure of approximately 2 psi is required to remove a sufficient amount of the element bow and twist so that the core can be considered as integral for structural, dynamic and thermal analysis purposes.

A typical example (Reference 2.1.3-3) of reactor assembly measurements is shown in Figure 2.1.3-3 in which measurements were made of core diameter at three axial stations as a function of the total bundling pressure. As both the mechanical bundling pressure and the dynamic parameter G_{BA} are proportional to the individual coil spring rate, the bundling requirement of 2 psi can be fulfilled by an equivalent G_{BA} value of 1.5 Gs.

In summary, the LSS dynamic G_{BA} requirements are:

- 1) $G_{BA} = .75$ Gs for space operation
- 2) $G_{BA} = 1.5$ Gs to maintain a minimum of 2.0 psi
mechanical bundling pressure
- 3) $G_{BA} = 2.0$ Gs for INT-21 launch.

2.1.3.3 General Geometric Relationship

Selection of the seal interface angle, θ , is based upon friction effects. One friction effect is lockup of the inner and outer seal segments as the core expands toward the reflector. Seal angles and their corresponding maximum tolerable friction coefficients at which lock up for core expansion would occur are as follows:

Seal Angle θ	45°	30°	15°
Friction Coefficient	.42	.58	.76

The second friction factor becomes effective during contraction of the core. The tendency would be of the inner segments to pull the outer segment off of its ledge if the friction coefficient between seals is excessive for a specific angle. Seal angles and their respective maximum tolerable friction coefficients to alleviate unseating of the outer seal segment are as follows:

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Figure 2.1.3-3. Bundling Pressure Versus Core Diameter

Seal Angle θ	45°	30°	15°
Friction Coefficient	1.00	.58	.25

Based upon the maximum tolerable friction coefficient for these two critical phases of functional operation, the seal interface angle, θ , has been established as 30 degrees.

Selection of the inner seal segment and plunger interface angle, α , is also based upon friction effects. The first friction effect is lockup at this interface during expansion of the core. The maximum tolerable friction coefficient for a specific angle would be as follows;

Angle α	45°	30°	15°
Friction Coefficient	.42	.48	.76

The second friction effect becomes active during contraction of the core. If the friction is excessive for a given α during this phase of operation, then the inner seal segment would not slide with respect to the plunger. This condition would cause the inner and outer seal segment surfaces to separate and cease to function as seals. The maximum tolerable friction coefficient acceptable to insure proper function at this interface is as follows:

Angle α	45°	30°	15°
Friction Coefficient	.41	.27	.14

It would appear that approximately 45° would be the desired angle; however, further consideration of the plunger is required. To achieve reduction of the bending stress developed in the plunger during expansion of the core, a minimal α is desirable. On this basis, the plunger and inner seal segment interface angle α has been selected as 30 degrees.

2.1.3.4 Material

The seal segments are made from ZTA graphite, PDS 30019-1. This material has been utilized in previous reactors NRX-A1 through NRX-A6.

The plungers are made from PO-3 graphite, PDS 30086-1. An alternate material for the segments could be PO-3; however, large size pieces of PO-3 are not readily available. Carb-I-Tex 700 segments have been vibration tested at room temperature in WANL's partial length core rig. Radiation data is not available and the cost of this material is high; however, if normal graphites show high friction in vacuum environments, Carb-I-Tex 700 may be a solution to the increase in friction due to wear-in of normal graphites as an extremely fine powdering of the surface of Carb-I-Tex occurs due to wear. Coated or impregnated graphites have been considered but development work has not progressed to the point where any of these materials can be recommended.

2.1.4 Springs for the Lateral Support

2.1.4.1 Introduction

Springs provide the radial force for the mechanical bundling and support functions of the lateral support. The springs are enclosed in capsules which are attached to the reflector aluminum structure (Figure 2.1.3-1). The function of the capsule is to provide a reaction load path for the radial force and to prevent radial leakage of coolant gas. The spring is conduction cooled through the capsule wall which is convectively cooled by coolant gas flow through the reflector. Deflection of the spring is a function of the relative motion of the core and reflector structure amplified by the seal and plunger angles of the lateral support components

2.1.4.2 Requirements

The springs are required to provide the force to the lateral support to assure that it transmits a mechanical bundling force equivalent to 2 psi upon the core elements. In conjunction with the friction of the lateral support components, the springs shall also provide the force required to achieve the dynamic breakaway level specified in the requirements of Section 2.1.3.2.

2.1.4.3 General Geometric Relationship

The plunger travel is greater than the relative motion of the core with respect to the reflector structure due to the angularity of the inner/outer seal segment and the inner seal segment/plunger interface surfaces. The plunger travel is equivalent to 1.333 times the relative motion of the core/reflector for the established seal and plunger angles of 30 degrees. Plunger travel is also affected by the compressibility of the insulation between the outer seal segment and the reflector structure. This additional plunger travel amounts to approximately 23 per cent of the insulation thickness with the utilization of 30 degree angle interfaces. The plunger length and diameter are determined in this study to preclude failure due to binding and stress (see Figure 2.3-6, Subroutine LSSCON Logic).

The spring length in this study is compatible with the reflector thickness required for nuclear considerations (Section 2.1.6) and the required plunger travel. The maximum outside diameter of the spring is based upon maintaining a minimum beryllium thickness between the control drum bore diameter, d_i , and the capsule diameter bore, H , of 100 mils (see Figure 2.1.4-1). The spacing between the capsule bore and beryllium segment centerline at the control drum radius, b , has also been established as 400 mils. The optimum thickness and width of the rectangular cross section of the spring wire is a product of this study. Radial thickness of the wire is limited by the material temperature allowable limitation. Section 3.1.4 of this study indicates the relationship of the outside diameter of the NSS with respect to the spring section for various "G" breakaway levels.

2.1.4.4 Materials

Candidate materials that have been considered for fabrication of this spring are listed in Table 2.1.4-1. Inconel 718 and A-286 were selected for determination of their effects upon optimization of the radial dimension of the NSS. Evaluation of Inconel 718 for this study is based upon stress limitation to below the proportional limit. Analysis has been performed which indicates that for cracks less than 12 mils deep, ductile stress limitation is more stringent than brittle stress limitation for Inconel 718 (Reference 2.1.4-1). The allowable stresses and shear modulus as a function of material temperature for Inconel 718, A-286, and Inconel 718 at its minimum proportional limit were established and documented for analysis of this spring (Reference 2.1.4-2).

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Figure 2.1.4-1. Spring and Reflector Geometry Relationship

TABLE 2.1,4-1

NUCLEAR AND RADIATION EVALUATION OF CANDIDATE SPRING MATERIALS (1)

Candidate Material	Type of Alloy	Reactivity Worth, ϵ / Kg	Reflector Photon Source Strength, MeV/sec
Udimet 630	Precipitation-hardening nickel-base super alloy	-0.66	1.6×10^{19}
Inconel 718	Precipitation-hardening nickel-base super alloy	-0.48	1.6×10^{19}
Rene 41	Precipitation-hardening nickel-base super alloy	-1.56	2.4×10^{19}
D-979	Precipitation-hardening nickel-base super alloy	-0.80	1.6×10^{19}
Udimet 700	Precipitation-hardening nickel-base super alloy	-2.25	2.9×10^{19}
Udimet 520	Precipitation-hardening nickel-base super alloy	-1.63	2.4×10^{19}
Alloy 901	Precipitation-hardening nickel-base super alloy	-0.54	1.6×10^{19}
Udimet 500	Precipitation-hardening nickel-base super alloy	-2.09	2.9×10^{19}
M-252	Precipitation-hardening nickel-base super alloy	-1.46	2.3×10^{19}
Waspalloy	Precipitation-hardening nickel-base super alloy	-1.77	2.6×10^{19}
Uni-Temp AF1753	Precipitation-hardening nickel-base super alloy	-1.79	2.1×10^{19}
Nimonic	Precipitation-hardening nickel-base super alloy	-2.03	2.8×10^{19}
Discalloy	Precipitation-hardening iron-base alloy	-0.46	1.6×10^{19}
A-286	Precipitation-hardening iron-base alloy	-0.56	1.6×10^{19}
SS-310	Solid solution strengthened iron-base alloy	-0.39	1.6×10^{19}
Cu-Be	Precipitation-hardening copper-base alloy	-0.58	1.6×10^{19}

(1) Based Upon Equal Volume of Spring Materials

2.1.5 Aluminum Structure

2.1.5.1 Introduction

The aluminum structure is one continuous member from the forward end of the core to the nozzle/reflector interface surface. The radial thickness of this structure is sized to limit the direct and buckling stresses to acceptable limits. Axial holes within the structure permit the passage of coolant flow to extract heat from the structure. Twenty-one axial rows of radial penetrations are provided for insertion of lateral support plungers. Thirty-six penetrations exist in each row to present a total of 756 radial plunger penetrations through the structure.

2.1.5.2 Requirements

The aluminum structure must comply with the requirements specified in the Reflector Assembly Specification No. EC-677559 which forms a part of CP-677555 NERVA NSS. The specified requirements which are prime factors in affecting the radial dimension are the axial support, lateral support function, thermal-hydraulic performance, and emergency operating mode.

The predominant factor affecting the radial thickness of the structure is the radial pressure drop which occurs at the aft end of this structure. The value utilized for this study is based upon the normal specification extreme of 852 psia specified as a WANL guideline for design and system studies. SNPO-C-1 establishes the direct stress limitation to be the lower of .85 times 99-95% of the minimum yield strength or .80 times 99-95% of the minimum ultimate strength and that the critical buckling pressure shall equal twice the maximum applied pressure.

2.1.5.3 General Geometric Relationship

Two general configurations are analyzed within this study. They are the ribbed structure and the structure without ribs, as shown in Figure 2.1.5-1. The overall radial thickness of the ribbed structure, including ribs, is greater than that of the structure without

Figure 2.1.5-1. Aluminum Structure

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ribs for the same strength. Minimizing the displacement of the beryllium reflector mass from the core yields a more efficient assembly from a nuclear consideration. The ribbed structure permits the average distance between the core and reflector to be less due to a thinner wall and also requires less aluminum mass due to its more efficient structural design. Previous analysis has indicated that the ribbed structure (Reference 2.1.5-1) can be sized by hoop stress (minimum material). However, the ribless structure (Reference 2.1.5-2) is critical in buckling (requiring material in excess of that required for acceptable hoop stress).

Relationship of the features of the aluminum structure and to interaction with other components in this study have been developed and documented (Reference 2.1.5-3) for input into the mathematical techniques section (2.3) of this study.

2.1.5.4 Materials

The aluminum structure material has been selected and documented as the result of a previous study (Reference 2.1.5-4). The material selected was 6061-T61.

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2.1.6 Beryllium Reflector (U)

2.1.6.1 Introduction (U)

(U) The beryllium reflector consists of beryllium segments and beryllium control drums located immediately outboard of the aluminum structure. Eighteen control drums provide the required control worth and, in conjunction with the 1134 segments, also provide the required reactivity. The radial thickness of this component is determined by the supply of sufficient beryllium mass to achieve the required reactivity worth, by the control drum size required to achieve the total control drum span requirement, or by the length of the lateral support spring containment capsule. The outer segment web thickness beyond the control drum is determined as a result, rather than a requirement, of this study. Items within the beryllium reflector are also presented in this section including a control drum bore liner, control drum clearance, and the control drum vane. A vertical section view is shown in Figure 2.1.6-1 for further clarification.

2.1.6.2 Requirements (U)

(U) The beryllium reflector must fulfill the requirements specified in the Reflector Assembly Specification No. EC-677559 which forms a part of CP-677555 NERVA NSS. The specified requirements which are prime factors affecting the radial dimension are the neutron reflection, thermal-hydraulic performance, reactivity control, and emergency operating mode.

(U) Nuclear reflection and reactivity control requirements are the predominant factors affecting the radial dimension of this component. The requirements specify that the reflector assembly shall satisfy the following:

(C-RD) Neutron Reflection - The reflector assembly shall satisfy the neutron reflection requirements consistent with the following criteria:

- a) The reactivity variation or control capability of the reflector assembly shall be \$4.50 at ambient conditions.
- b) The reflector assembly shall be compatible with a maximum fuel loading in a graphite matrix core of 630 mg/cc.

Figure 2.1.6-1. Beryllium Reflector Section

- c) The reflector assembly shall be compatible with a core having a maximum reactivity shim content of \$1.50.

It is assumed that the requirement for the maximum uranium loading in the 30 volume percent composite fuel design is 700 mg/cc compared to the 630 mg/cc for graphite fuel matrix requirement.

Control Drum Reactivity Span - The reflector assembly shall incorporate 18 control drums which provide the capability of reactivity adjustment at room temperature and without propellant flow of \$4.50 minimum based on a start-of-life cold critical of \$TBD. Further, this reactivity shall be based on 170 degrees of rotation of the drums.

In order to verify that a particular reactor design does provide the required control drum span, extensive neutronic calculations are performed. Experience has shown that there is a bias between the calculated drum span values and that measured for the reactor simulated by the calculation. The ratio of the measured to calculated drum span will be used in the following discussion to develop (1) an average value for the experimental/analytical bias and (2) the safety margin that must be allowed in order to assure that the drum span of the reactor design being evaluated will satisfy the 4.5\$ requirement.

To allow use of a common statistical method for the calculation of these two factors, a first step is the determination of the underlying population frequency distribution. Data satisfying a "normal" distribution plotted on a probability scale of cumulative frequency will fall on a straight line. For the four data points used in this study (Reference 2.1.6-1), it appears that the non-normality is not great enough to be detected by the available sample. This permits statistical treatment of the data using the equations from "normal" distribution theory to calculate the parameters that characterize the population from which the four data points have been taken. The estimate of the population mean (M) and standard deviation (S) is 0.873 and 0.022, respectively. These two parameters are used to develop a measured to calculated ratio consistent with the desired probability and confidence levels. The ratio to be applied to the calculated drum spans in order to assure that the drum span of the reactor design being evaluated will satisfy the requirement is calculated as $(M - KS)$

where K is a factor to account for (1) the size of the sample used to estimate the population parameters, (2) the desired confidence level and (3) the fraction of the population that is included. These values are plotted in Figure 2.1.6-2. For this study, the predicted drum span for the base design has been developed using the mean ratio (0.873). In the NSS optimization calculations, this ratio is varied from 0.873 to 0.718 to assess its effect.

2.1.6.3 General Geometric Relationship

Placement of the beryllium mass with respect to the core will be affected primarily by the two aluminum structure configurations to be analyzed as the core, periphery, and lateral support are fixed as specified in Sections 2.1.1, 2.1.2, and 2.1.3, respectively. The ribbed structure would require less total beryllium from a reactivity consideration because of the more effective placement of the reflector nearer to the core. However, for a given outside diameter, the ribbed configuration would restrict the control drum to a smaller diameter than that of the ribless configuration. This is due to the fact that the rib can not be notched for the drum, consequently, the drum centerline would be further from the core and the reflector thickness may be dictated by the control drum size required to achieve the control worth requirement.

The base case configuration analyzed in this study is the ribbed design, as previously shown in Figure 2.0-2. Figure 2.1.6-1 illustrates the various cavities and holes in the reflector required for the reflector assembly to satisfactorily perform its many functions specified in EC-677559. The most notable removal of reflector material is caused by the cavity required for the lateral support capsule which encloses the lateral support spring. The cavity diameter is limited to preclude material breakout in the control drum bore area of the beryllium segment. If the "G" capability of the lateral support system is not achieved within the maximum diameter spring permitted, then a longer spring would be required and the thickness of the reflector would be established by "G" capability requirements rather than nuclear requirements.

WITH THE SPECIFIED CONFIDENCE LEVEL, AT LEAST P
PERCENT OF THE CORRECTION FACTORS WILL BE GREATER THAN THAT SHOWN

Figure 2.1.6-2. Lower Limit of the Drum Span Correction Factor for Various Proportions (P) and Confidence Levels

(U) The neutronics of the base case configuration and corresponding perturbations were calculated using the Westinghouse Integrated Nuclear, Radiation and Shielding Standard Design Method (WISDM) (Reference 2.1.6-1). The purpose of WISDM is (1) to systematize and improve the reliability and accuracy of all neutronic calculations and (2) to insure consistency between the nuclear and the radiation/shielding calculations.

(C-RD) Regionwise energy spectra generated for the aluminum structure design in the Reflector Trade Study No. 763 were utilized in this study. Both the high CTE graphite and composite fuel designs are design variables. EXTERMINATOR calculations which were performed utilized the high CTE graphite fuel calculational model which was used in the Reflector Trade Study No. 763. The reactivity differences between the high CTE and composite fuels are calculated; however, the calculated total control drum span for the graphite and the 30 v/o composite fuels are the same.

(U) R-0 EXTERMINATOR calculations were performed at the 0° and 180° control drum positions to determine the total control drum span for the base case configuration. Table 2.1.6-1 summarizes the physical parameters for this case. EXTERMINATOR calculations and a 0.873 mean experimental normalization factor result in a total predicted control drum span of \$3.85. To achieve the \$4.5 total control requirement requires an increase in the control vane outer diameter of 0.22 inch. Thus, the R-1 control vane outer diameter for the base case configuration must be increased from 3.35 to 3.57 inches.

(U) The two most significant changes relative to the previous R-1 aluminum structure reflector designs which affected the base case total control drum span are 1) the non-corrodible periphery and 2) the increased lateral support spring size.

TABLE 2.1.6-1.

PHYSICAL PARAMETERS FOR BASE DESIGN - DWG. NO. 982D265

Geometry		Masses		
Region	Outer Radius, cm	Region	Element	Mass, KG
Core	47.388	1. Periphery	Carbon	109.16
			Zirconium	170.27
			Stainless Steel	9.90
Periphery	49.468	2. Lateral Support	Carbon	190.36
Lateral Support	53.760	3. Plunger	Beryllium	21.31
			Aluminum	69.45
Aluminum Structure	55.843		Carbon	12.66
			Inconel	17.23
Inner Beryllium (Ribs)	58.485	4. Spring	Beryllium	121.51
			Aluminum	39.72
Drum Centerline	63.450		Inconel	68.18
		5. Aluminum Cylinder	Aluminum	168.86
Outer Beryllium	68.543			
		6. Inner Beryllium	Beryllium	143.69
			Aluminum	29.65
Beryllium Reflector Thickness	5.0 inches	7. Outer Beryllium	Beryllium	593.35
			Aluminum	43.17
Control Vane O. D.	3.35 inches			

1. The non-corrodible periphery introduces 10 kg of stainless steel and 178 kg of zirconium in the R-1 periphery. EXTERMINATOR runs with the same geometry show that the non-corrodible periphery material results in a reduction in the total drum span of 32 cents relative to the graphite filler strips. In addition, the non-corrodible design results in an outward reflector movement causing a further reduction in drum span of approximately 15 cents. The total effect requires an increase in the control vane outer diameter of 0.16 inch.
2. Larger spring size requires an increase in the spring cavity in the reflector assembly resulting in a decrease in the beryllium mass of approximately 48 kg. The drum span coefficient for beryllium in the outer reflector region has been calculated with the current set of EXTERMINATOR problems to be equal to + 0.91 cents/kg. The resulting loss in drum span due to this beryllium removal is approximately 40 cents. The R-1 spring mass of Reflector Trade Study No. 763 was approximately 97 lbs. The current base case spring mass is approximately 150 lbs. A drum span worth coefficient was derived for inconel in the spring region from the set of EXTERMINATOR calculations performed for this study. This drum span coefficient is -1.9 cents/kg for a span reduction of approximately 45 cents. The total effect on drum span, due to the lateral support spring size, is equal to a reduction of 85 cents which can be compensated by an increase in the control vane outer diameter of 0.28 inch.

The total effect of the non-corrodible periphery and increased spring size results in a loss in drum span of \$1.32 which would necessitate an increase of 0.44 inch in the vane O. D. to maintain a drum span of \$4.50.

Adequate removal of heat from the control vanes, beryllium segments and drums is achieved by placement of coolant holes and passages around or through these components. Control drum clearance and installation of the drum bore liner cans (Reference 2.1.6-2) all detract from the reflector worth by removal of beryllium material or, in other words, increase the void fraction of the reflector.

2.1.6.4 Materials

The segments and control drums are manufactured from hot pressed beryllium. The control vanes are fabricated from copper-boron¹⁰ plates. The volume percent of boron¹⁰ contained within the vanes is 18% for the reference case. The copper-boron¹⁰ material was selected over that of aluminum-boron¹⁰ in a previous study (Reference 2.1.6-3). The drum bore liner and drum can are made from 6061-T6 aluminum.

2.1.7 Aluminum Can

2.1.7.1 Introduction

The aluminum can is the component which surrounds the outside of the beryllium reflector. Considerations which affect the radial thickness of this component are both analytical and manufacturing feasibility limits. The function of this component is to provide a coolant flow baffle between the reflector beryllium components and the reflector-pressure vessel flow gap.

2.1.7.2 Requirements

The aluminum can must comply with the requirements specified in the Reflector Assembly Specification No. EC-677559 which forms a part of CP-677555 NERVA NSS. The specified requirements which are prime factors in affecting the radial dimension of this component are thermal-hydraulic performance and general design features.

The aluminum can shall comply with the structural requirements specified in SNPO-C-1 pertaining to direct and combined stresses.

2.1.7.3 General Geometric Relationship

A uniform thickness aluminum can, over the 52 inch axial length, is analyzed in this study. Its thickness is dependent upon the radial pressure gradient imposed upon it and the configuration of the beryllium segments against which they contact. If beryllium segment webs beyond the control drums are deleted, then the thickness of the can may be dictated by limitation of the permissible inward deflection of the can across the web void span to prevent contact of the drum bore liner.

Relationship of the features of the aluminum can and to interaction have been developed and documented (Reference 2.1.7-1) for input into the mathematical techniques section (2.3) of this study.

2.1.7.4 Materials

The aluminum can material is 6061-T6. Material properties, as a function of temperature, have been documented in the analysis of this component (Reference 2.1.7-2).

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2.1.8 Flow Gap

2.1.8.1 Introduction

The flow gap located between the aluminum can and the pressure vessel provides for passage of the propellant utilized to cool the pressure vessel. This radial gap must also be adequate to prevent interference of the reflector assembly and the pressure vessel during all phases of reactor operation.

2.1.8.2 Requirements

The flow gap must comply with the requirements specified in the Reflector Assembly Specification No. EC-677559 which forms a part of CP-677555 NERVA NSS. The specified requirements which are prime factors in affecting the radial dimension are thermal-hydraulic performance and interface requirements.

2.1.8.3 General Geometrical Relationship

Sizing of the flow gap is based upon relative motion of the aluminum can and the pressure vessel. Responsibility of the pressure vessel lies with ANSC, however, evaluation of its characteristics are required for this study. The pressure vessel material selected by ANSC is 7039-T63 and the wall thickness indicated is 730 mils (Reference 2.1.8-1).

2.1.8.4 Materials

Not applicable.

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2.2 DESIGN PARAMETERS INVESTIGATED (U)

(U) This section discusses the design parameters which are investigated in this study, including both those parameters which are considered in the computerized design program and those which are selected from other considerations. Design parameters selected from other considerations are considered as fixed parameters in the computerized design program. The variable parameters investigated in this study are tabulated in Table 2.2-1, Page 2-51.

(U) The overall fixed conditions for the design study are:

- 1) Reference design forward of station zero and aft of station 52.
- 2) Uniform geometry for stations between 0 and 52.
- 3) Component design concepts per previous trade study recommendations.
- 4) Reference design fluid conditions in plenums.
- 5) Design based on nominal rated and throttled (~ 60% power) conditions except for use of spec extreme for structural loads.

(CRD) 2.2.1 Core (U)

2.2.1.1 Fixed Parameters (U)

- (C-RD)
- 1) Element size and geometry; 753 mils hexagonal with 19 coolant holes.
 - 2) Number of elements; 1878 fueled, 349 centrals.
 - 3) Coating design.
 - 4) 630 mg/cc maximum loading in graphite elements.
 - 5) SSA design.
 - 6) Nominal bundling pressures.
 - 7) Chamber conditions.
 - 8) Hydrogen content.
 - 9) Shim capability, \$1.50.

2.2.1.2 Variable Parameters (U)

(U) In the computerized design program, the fuel element material is the only input variable for the core (see Figure 2.0-1). The two candidate fuel matrix materials, AXF

and composite, are represented by their mass and thermal expansion characteristics. The composite fuel material has the largest thermal expansion (1.802% over room temperature dimension) and was used to set the radial space requirement for the lateral support system (Section 2.1.3). The calculated weight of the AXF graphite core is 5320 lbs. and the composite core weight is 7330 lbs. These weights include all of the mass which must be supported by the lateral support system. Briefly, this includes the core, periphery, and that portion of the lateral support system which is not fixed (movable seal segments and plungers).

(U) Functional relationships are used to establish the fuel coolant exit temperature, fuel coolant flow rate, core mass, and core diameter at rated conditions. The first two of these internal variables are dependent on the core bypass flow and its exit temperature for a fixed chamber condition. The effort required to develop a long life fuel is related to the fuel coolant exit temperature.

2.2.2 Core Periphery (U)

2.2.2.1 Fixed Parameters (U)

- (C-RD)
- 1) O. D. at assembly conditions, 38.951 inches.
 - 2) Mass of components.
 - 3) Combined insulation and radial flow barrier thickness of 0.275 inch (Section 2.1.2).
 - 4) Pyrofoil wrapper seal between stations 4.5 and 17.0.
 - 5) 75 v/o ZrO_2 - 25 v/o ZrC composite insulation aft of Section 17.0.
 - 6) Full length stainless steel wrapper.
 - 7) 87 mils minimum radial edge thickness on filler strip.
 - 8) Stresses assumed acceptable.
 - 9) Hydrogen content.

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2.2.2.2 Variable Parameters

The core periphery computerized design process involves only internal variables (see Figure 2.0-1). Functional relationships are used to establish the outer diameter at rated conditions and the core bypass flow rate and exit temperatures. The first variable here is dependent on the fuel diameter at rated condition. The core bypass flow and its exit temperature are dependent on the heat transferred from the core periphery--lateral support region into the aluminum structure if a fixed maximum wrapper temperature is to be maintained.

2.2.3 Lateral Support

2.2.3.1 Fixed Parameters

- 1) Basic seal and plunger concept.
- 2) ZTA seals, PO 3 plungers, grafoil insulation.
- 3) Friction coefficients.
- 4) Grafoil I. D. at assembly conditions, 42.171 inches.
- 5) Inner/outer seal angle and inner seal/plunger angle, 30° .
- 6) Number of rows of seals, 21.
- 7) Hydrogen content.
- 8) Seal ring stresses assumed acceptable.

2.2.3.2 Variable Parameters

The lateral support computerized design process involves one input variable--thickness of the grafoil insulation at the aluminum structure I. D. (see Figure 2.0-1). The range of thickness considered for this study is from zero to 80 mils.

Thickness of the insulation at the aluminum structure I. D. affects the relationship between structure temperature, heat transferred into the structure from the lateral support seal region, core bypass flow, and the wrapper temperature. From the standpoint of maintaining acceptable temperatures in the structure with minimum coolant flow, the

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insulation should be as thick as possible. However, thicker insulation necessitates an increased core bypass flow to maintain a fixed wrapper temperature. Thicker insulation also results in an increase in the distance between the core and the beryllium reflector, hence an increased reflector thickness.

Insulation 80 mils thick was found to result in an acceptable aluminum structure temperature when the core bypass flow and lateral support temperatures insulation can be used with the metal wrapper design because of the reduced operating temperature of the core periphery and lateral support seal components.

The maximum insulation thickness is set by the aluminum structure ledge which supports the fixed lateral support seals. The minimum effective ledge width of 70 mils is maintained with the utilization of insulation up to 80 mils. Greater total insulation deflection also occurs with thicker insulation which is further amplified by a factor of three for the additional radial motion which the plunger and spring must accommodate due to the 30° seal angle configuration.

2.2.4 Lateral Support Springs

2.2.4.1 Fixed Parameters

- 1) 21 rows of springs.
- 2) 36 springs per row.
- 3) Spring to capsule and capsule to beryllium segment clearances.
- 4) External convection cooled aluminum spring capsules.
- 5) Friction coefficients ($\mu = .18, .30, \text{ and } .35$ for breakaway, stress, and binding respectively).
- 6) Minimum beryllium wall thickness of 100 mils at tangency of capsule and drum bore in beryllium segments.

2.2.4.2 Variable Parameters

The computerized design process for the lateral support springs includes the "G" breakaway, spring wire thickness, and spring material as input variables (see Figure 2.0-1). The plunger and spring sizes are dependent on these input variables and also upon the core mass.

The lateral support springs are sized to prevent initiation of relative lateral motion between the core and the reflector assembly, as specified in EC-677559, for loads up to the selected "G" breakaway value. This study considers a range of breakaway up to 4 "Gs" to determine the effect upon the overall radial dimension. Ideally, the thickness of the beryllium reflector established from nuclear considerations would be compatible with the length, outside diameter, and the wire section of the spring for obtaining the "G" breakaway capability. The spring outside diameter and wire section can be increased in an attempt to obtain the specified "G" level with the minimum reflector thickness determined by nuclear considerations. The maximum outside diameter of the spring is dependent upon maintaining a minimum wall thickness in the beryllium segments where the vertical drum bore and the horizontal LSS cavity become tangent. The maximum wire thickness is dependent upon the operating temperature limitation of the spring material. Where maximum O. D. and wire section spring dimensions do not satisfy the "G" breakaway requirement, the spring length could be increased to achieve the requirement, hence establishing reflector thickness upon "G" breakaway requirements rather than nuclear requirements.

2.2.5 Aluminum Structure

2.2.5.1 Fixed Parameters

- 1) 6061-T61 aluminum structure material.
- 2) Nominal specification extreme radial pressure of 852 psia.
- 3) Direct stress limited to lower of 0.85 times 99-95% of minimum yield strength or 0.80 times 99-95% of minimum ultimate strength.
- 4) Critical buckling stress equals twice the maximum applied pressure.

- 5) Maximum nominal aluminum temperature 600°R.
- 6) Average coolant temperature equal to reflector assembly average coolant temperature.
- 7) 756 radial penetration holes for installation of lateral support plungers.

2.2.5.2 Variable Parameters

The computerized design process for the aluminum structure considers two types of structure geometries--ribbed and non-ribbed (see Figures 2.0-1 and 2.1.5-1). Other variables affecting the aluminum structure design are the aluminum temperature, cooling hole geometry, plunger size, and structure I. D. The aluminum temperature and cooling hole geometry are, in turn, dependent on the structure thickness, the heat conduction into the aluminum from the lateral support region, and the reflector total heating and coolant flow.

2.2.6 Beryllium Reflector

2.2.6.1 Fixed Parameters

- 1) Basic aluminum structure reflector assembly design concept selected in Trade Study No. 763.
- 2) \$4.50 drum span including corrosion loss of \$1.00.
- 3) 18 control drums.
- 4) 756 lateral support spring capsule cavities.
- 5) 100 mils thick copper-boron¹⁰ control vane which spans an arc of 120°*.
- 6) Drum bore in beryllium segments 550 mils greater than control vane outside diameter.
- 7) No beryllium outer web unless required for reactivity.
- 8) Minimum control drum center line diameter consistent with required drum diameter.

*The R-Θ EXTERMINATOR code was used to calculate and plot a curve of relative drum span vs. vane arc and is shown in Figure 2.2.6-1 (Reference 2.2.6-1).

Figure 2.2.6-1. Optimization of Control Vane Angle

- 9) 75 mils radial control drum clearance--based upon satisfactory previous reactor operation.
- 10) Stress in beryllium components assumed acceptable--typical ΔT calculated as a function of design.

2.2.6.2 Variable Parameters

The beryllium reflector computerized design process considers control vane boron density and drum span uncertainty as input variables (see Figure 2.0-1). The beryllium thickness and control drum size are dependent on reactivity, drum span and LSS spring geometry considerations. The thickness of the beryllium is determined by the consideration which results in the largest value for this thickness. The reactivity and drum span are dependent on the component masses, radial location, and the reflector coolant hole and spring capsule cavity voids.

The effect of control vane surface density is shown in Figure 2.2.6-2. These data were generated using R- Θ EXTERMINATOR calculations and previously reported in Reflector Trade Study No. 763. The curve has been renormalized to correspond with this base case design (Reference 2.2.6-1). The initial slope of the worth curve is set primarily by absorption of thermal neutrons. Increases in the surface density beyond 0.100 gm/cm^2 increase the epithermal and fast absorptions at a much reduced rate. For the NERVA reactor $.080$ to $.130 \text{ gm/cm}^2$ represents a practical optimum poison density range.

The limit of 0.100 gm/cm^2 (18 v/o boron¹⁰) has been established as an upper limit for the surface density due to manufacturing experiences. Flat plates have been produced successfully up to 0.130 gm/cm^2 ; however, subsequent fabrication into the vane curvature configuration has caused surface and end cracking of the vanes; alleviation of this problem will occur with the loading limited at 0.100 gm/cm^2 .

Figure 2.2.6-2. Control Vane B^{10} Surface Density, gm/cm^2

2.2.7 Aluminum Can

2.2.7.1 Fixed Parameters

- 1) The wall thickness of this component is uniform.
- 2) The material is 6061-T6 aluminum.

2.2.7.2 Variable Parameters

No input variables are considered in the computerized design process for the aluminum can (see Figure 2.0-1). A minimum thickness of 65 mils is specified for this component based upon manufacturing considerations. The final thickness to be specified will be dictated by either compliance with an acceptable thermal-stress level or the minimum manufacturing thickness.

2.2.8 Flow Gap

2.2.8.1 Fixed Parameters

- 1) Pressure vessel 730 mils thick.
- 2) Pressure vessel material is 7039-T63 aluminum.
- 3) Maximum pressure vessel temperature is 735°R.
- 4) Flange area effects of the pressure vessel are neglected.
- 5) The gap at assembly conditions is 160 mils.

2.2.8.2 Variable Parameters

The computerized design process for the flow gap does not include any input variables (see Figure 2.0-1). However, the annular flow gap, at operating conditions, affects the temperatures of the aluminum structure, beryllium reflector, aluminum can, and pressure vessel. The minimum coolant flow rate is related to limiting the pressure vessel temperature to an acceptable value. A large gap results in large flow rate requirements

to provide acceptable convection heat transfer coefficients along the pressure vessel surface. However, the gap must be large enough to prohibit interference of the reflector assembly and pressure vessel during all operating conditions. Initial calculations indicate that the 160 mils specified is acceptable for non-contact (Reference 2.2.8-1).

TABLE 2.2-1
SUMMARY TABLE OF VARIABLE PARAMETERS

<u>Component</u>	<u>Variable</u>	<u>Range or Value Considered</u>	<u>Limit</u>
Core	Weight	5320 lbs. (graphite)	-
		7330 lbs. (composite)	-
LSS Insulation	Grafoil Thickness	0-80 mils	80 mils max.
LSS Springs	"G" Capability	2-4 "Gs"	-
	Material	A-286, Inconel 718	-
	Size	Determine:	
		1) length	-
		2) O.D.	-
3) wire base		-	
4) wire thickness	200 mils max.		
Aluminum Structure	Ribbed Configuration	Determine Thickness	-
	Ribless Configuration	Determine Thickness	-
Beryllium Reflector	Thickness	Determine Thickness	-
Control Vane	Arc	0°-360°	120° (Fixed)
	Surface Density	.080-.130 gm/cm ² (12-24 v/o B ¹⁰)	.100 gm/cm ² (18 v/o B ¹⁰ max.)
	Probability of Achieving \$4.50 Drum Span	50-99%	-
Aluminum Can	Thickness	≥ 65 mils Determine Thickness	65 mils min.

2.3 RADIAL SIZING PROGRAM (RSP)

Figure 2.3-1 shows the logic for the radial sizing program, RSP, that was developed to simulate the design process shown in Figure 2.0-1. For the program, the arrangement of the design operations has been chosen to facilitate loop control and convergence. The design process included in each subroutine (block) consists of all the functional relationships from particular disciplines. Subroutine THERMAL includes all of the thermal design functional relationships as well as the radiation heating relationships, subroutine STRESS includes all of the structural design functional relationships, subroutines NUKE and GEOM contain all of the nuclear design functional relationships and supporting geometry relationships, and subroutine LSSCON contains all of the functional relationships related to the lateral support design. The primary functions which each subroutine performs are listed below the blocks. Final convergence is provided by comparing the dimensional change between successive iterations with an arbitrary criterion, ϵ . The logic provides for initial sizing of the beryllium thickness from nuclear considerations. If the largest LSS spring permissible for this reflector size does not provide the specified "G"breakaway, the reflector thickness is increased (using maximum diameter springs) until the specified "G"breakaway is achieved.

Figures 2.3-2 through 2.3-6 develop the logic that is contained in each subroutine. Subroutine THERMAL logic is given on Figure 2.3-2. Using the inputs indicated, the subroutine computes the total nuclear heating in the reflector assembly components and the heat conducted in from the lateral support system. References 2.3-1 and 2.3-2 contain the details of the analyses and data used to support these calculations. The coolant flow distribution, material average and maximum temperatures, material temperature differences, and average hydrogen density are then calculated for the various components as functions of core station and operating condition as indicated on Figure 2.3-2. Reference 2.3-3 establishes the detailed functional relationships contained in this subroutine.

*Note: Beryllium thickness is first set by nuclear considerations with best possible spring even though "G" Breakaway is not satisfied, K = 1: then beryllium thickness is increased to satisfy "G" Breakaway, if necessary, K = 2. Both solutions are output.

Figure 2.3-1. Radial Sizing Program Logic

Figure 2.3 - 2 Subroutine THERMAL Logic

Figure 2.3 - 3 Subroutine STRESS Logic

Figure 2.3 -44 Subroutine NUKE Logic

Figure 2.3-5 Subroutine GEOM Logic

Figure 2.3-6. Subroutine LSSCON Logic

Figure 2.3-3 gives the subroutine STRESS logic. Starting with a reference configuration for the aluminum structure, the minimum cylinder thickness required to support the radial pressure drop is determined based on the primary stress limit established by SNPO-C-1 and the assumed rib dimensions. Using the calculated cylinder thickness, the assumed rib geometry is modified to achieve a margin of safety of one for buckling as required by SNPO-C-1. If no ribs are used, the cylinder itself is sized to resist buckling. These calculations are repeated until the minimum cylinder thickness and rib geometry which satisfy both the direct stress and buckling requirements are determined. The radial deflection of the structure as a function of core station is then calculated for use in the lateral support and peripheral can calculations.

The process of specifying the can geometry required for the design consists of determining the thickness needed to satisfy the following conditions:

1. The uniform hoop stress caused by pressure is equal to the primary stress limit.
2. The uniform hoop stress caused by the combination of pressure and thermal interference is equal to the secondary plus primary stress limit.
3. The direct hoop stress plus bending stress caused by an inward acting radial pressure drop is equal to the primary plus bending stress limit.
4. The local radial deflection of the can is 0.020 inch.

Conditions 3 and 4 are applied only if there is no O. D. beryllium web at the control drum centerline. This would leave the can unsupported in this region. Also, condition 2 is not used directly to set the can thickness. Instead, it is used to set the assembly clearance between the can and the reflector. The can thickness selected is the largest value needed to satisfy the above criteria. After determining the can thickness needed, its deflections are calculated for use in the pressure vessel operating gap calculation which follows.

The pressure distribution along the pressure vessel annulus and the temperature of the pressure vessel are used to calculate the pressure vessel deflection. This is combined with the can deflection calculated above to determine the change in the pressure vessel annulus at the operating condition. This operating gap is used in the subroutine THERMAL to calculate the maximum temperature in the pressure vessel. The stress in the pressure vessel is computed and printed out as a function of core station for information only. References 2.3-4 and 2.3-5 establish the details of the functional relationships given in subroutine STRESS.

Figure 2.3-4 shows the logic for subroutine NUKE. For each of the variable design parameters, the resulting changes in reactivity and total control drum span are calculated relative to the base case design value. Basically, movement and mass worth coefficients generated from EXTERMINATOR data are applied to the resulting dimensional and mass changes from the base case values. The resulting reactivity changes and drum span changes are then totaled. The drum span change is converted to a change in the control vane outer diameter and the reflector is resized using the calculated vane O. D., allowance for drum cans and gaps, beryllium outer web dimension and the aluminum rib length.

The effect on the maximum fuel loading is also calculated for the High CTE graphite and Composite fuel by converting the change in beryllium thickness resulting from the change in vane O. D. into a reactivity effect and combining it into the total reactivity change. Reference 2.3-6 establishes the details of the functional relationships used in NUKE and presents the EXTERMINATOR results from which the relationships were generated.

Figure 2.3-5 shows the logic for subroutine GEOM. This subroutine calculates the mass changes (by region) relative to the reference design. These mass changes are used by subroutine NUKE as discussed above. Reference 2.3-7 gives the geometry relationships used in subroutine GEOM.

Figure 2.3-6 shows the logic for subroutine LSSCON. Two basic independent variables are adjusted to meet the requirements. These are the spring mean diameter, D_s , which is changed to fit a spring design within a radial reflector envelope set by nuclear considerations, and the inner radius of the outer reflector can, R_{can} , which is changed in the event that an acceptable spring design cannot be found within the nuclear design envelope. The other spring, plunger, and capsule dimensions are adjusted as functions of D_s and R_{can} .

For fixed values of the independent variables, the plunger length is set so that no binding occurs during operation based on a fixed installation length of plunger inward of the reflector (plunger overhang). The thickness of the capsule wall is determined by considering the buckling load acting on it. Using a spring solid height dimension compatible with the calculated plunger length, allowable shear stresses and spring material properties computed as a function of spring temperature, and spring maximum motions compatible with the type of core and the reflector design, the axial dimension of the rectangular spring coil and the spring rate are found. The basic equations are nonlinear and include correction terms involving the dependent variables.

Using the computed spring and plunger parameters, the lateral support system vector equations are solved for significant friction coefficients and the computed plunger stress and G capability are checked against requirements. If the requirements are not met, the plunger diameter is adjusted for the stress capability while the respective independent parameter is incremented to modify the dynamic capability and the program returns to the spring, plunger, capsule dimension section.

References 2.3-8 through 2.3-10 establish the detailed functional relationships and material properties used in subroutine LSSCON.

These subroutines, under the control of the RSP main program provide a set of radial dimensions which simultaneously satisfy all of the programmed design requirements. Reference 2.3-11 describes the entire RSP main program in more detail, giving users' instructions, source program listing, and sample problems.

3.0 RESULTS

The results from the computerized design program are given in the following sections. Eight variable design parameters are considered. These parameters are :
(1) the fuel element matrix material, (2) the thickness of Grafoil insulation at the I.D. of the aluminum structure, (3) the "G" breakaway level for the lateral support system, (4) the lateral support spring wire material, (5) the thickness of the spring wire material, (6) the configuration of the aluminum structure (i.e., ribbed vs non-ribbed cylinder), (7) the B_{10} surface density of the control vanes, and (8) the probability of achieving the required \$4.50 control drum span. For each specified set of values for these eight design parameters, the computerized design program defines a design which meets the programmed design requirements. The effect which each design parameter has on the O. D. of the NSS is shown by fixing seven of the parameters and generating designs as a function of the remaining parameter. The values of the seven fixed design parameters are noted on each of the resulting functions. The O. D. (at assembly conditions) of the aluminum can which encloses the beryllium reflector will be referred to as the NSS O. D.

3.1 EFFECTS OF DESIGN PARAMETERS ON NSS O. D.

3.1.1 B_{10} Surface Density of Control Vanes

The effect of the B_{10} surface density on the NSS O. D. is shown on Figure 3.1.1-1. Increasing the B_{10} surface density results in reduced values of the NSS O. D., but the rate of reduction of O. D. with surface density lessens with increasing surface density due to the relationship shown on Figure 2.2.6-2. Figure 3.1.1.-1 also indicates that the effect of B_{10} surface density is not dependent on the configuration of the aluminum structure. Values of B_{10} surface density in excess of the current manufacturing limit of 0.10 gm/cm^2 (18 v/o B_{10}) can provide only a relatively small reduction in the NSS O. D. The limiting value of 0.10 gm/cm^2 has therefore been selected as the fixed value for this design parameter in studying the effects of the remaining parameters.

Figure 3.1.1-1 Effect of B_{10} Surface Density in Control Vane

3.1.2 Grafoil Thickness at I. D. of Aluminum Structure

The thickness of the Grafoil insulation at the I. D. surface of the aluminum structure affects the NSS O.D. as shown on Figure 3.1.2-1. The NSS O.D. increases with increasing Grafoil thickness in a nearly linear relationship, and the magnitude of the NSS O.D. increase is approximately one inch for an increase of Grafoil thickness from zero to 0.080 inches. This relationship is also shown to be independent of the configuration of the aluminum structure. Figure 3.1.2-2 shows the effect of varying the Grafoil thickness at other values of "G" breakaway. Comparing the two curves for the "Ribbed" aluminum structure, it is seen that for "G" breakaway greater than 1.5 the difference in the NSS OD for the two Grafoil thicknesses is fairly constant at one inch. At values of "G" breakaway less than 1.5, the difference in OD decreases because the thickness of the beryllium becomes less dependent on the lateral support requirements. A similar behavior is shown for an aluminum structure with no ribs, but the effect at "G" breakaway values between 1.0 and 1.5 is less pronounced.

These results indicate that, from the standpoint of providing a minimum NSS O.D., the "best" design is one with no Grafoil insulation at the aluminum structure I.D. The RSP output also showed that the temperature of the aluminum structure could be maintained at acceptable values with no insulation at the I.D. of the structure. However, the thermal conditions in the core periphery and lateral support regions used in this study were typical of a design having relatively high coolant flow rates and relatively low operating temperatures. Because the lateral support and core periphery regions are the subjects of further conceptual trade studies, it is felt that providing 0.030 inches of Grafoil at the I.D. of the aluminum structure would represent a better design approach. This would provide some degree of flexibility to accommodate contingencies in the design of the lateral support and core periphery regions.

Figure 3.1.2-1 Effect of Grafoil Thickness at Aluminum Structure ID

Figure 3.1.2-2. Effect of Grafoil Thickness as a Function of Lateral Support "G" Breakaway

It was also found that the strong sensitivity of the NSS O.D. to the thickness of the Grafoil insulation is due to the increased plunger overhang (the plunger is not supported in the Grafoil region) and the increased plunger travel (the Grafoil is somewhat compressible). It was decided to consider a means of supporting the plunger to eliminate the increased plunger overhang and to include 0.030 inches of Grafoil in the design. The computerized design program was modified to represent a plunger guide extending through the 0.030 inches of Grafoil. The results given in most of the figures that follow reflect this design philosophy and it is noted on the figures.

3.1.3 Probability of Achieving \$4.50 Drum Span

Figure 3.1.3-1 shows the effect of drum span probability (at 95% confidence level) on the NSS O.D. for two thicknesses of Grafoil insulation. This figure does not include the revisions discussed above relative to extending the plunger guide. The NSS O.D. increases with increasing probability of achieving the required drum span, and the rate of increase also increases as the probability level increases. This occurs because the drum span which the design must provide on a calculated basis increases sharply as the probability of achieving the required drum span approaches 100%. The relationship shown indicates that using a drum span probability of 80% represents a reasonable compromise between achieving the required drum span and providing a minimum NSS OD. Therefore, the effects of the remaining design parameters are studied using an 80% probability of achieving the required \$4.50 drum span with a 95% confidence level.

3.1.4 Lateral Support Spring Wire Thickness

Figure 3.1.4-1 shows the effect of the lateral support spring wire thickness, a , on the NSS OD. The family of lines for fixed values of "G" breakaway indicates that there is an optimum spring wire thickness (i.e., a wire thickness which provides minimum NSS OD) and it is a function of the "G" breakaway requirement. At small values of "G" breakaway, the NSS OD is not strongly dependent on the spring wire thickness and the optimum wire thickness is relatively small. As the "G" breakaway requirement

Figure 3.1.3-1 Effect of Drum Span Probability

Figure 3.1.4-1 Effect of Lateral Support Spring Wire Thickness

increases, the NSS O.D. becomes more strongly dependent on the wire thickness, and the optimum wire thickness increases. The ratio of the wire dimensions, a/b , is also indicated on this figure. A value of a/b of 2.0 is very near to the locus of the optimum points on the family of constant "G" breakaway curves. The heavy line on this figure indicates the division between designs having a value of $K = 1$ and $K = 2$. K was defined on Figure 2.3-1. In the $K = 2$ region, the NSS O.D. is much more strongly dependent on the spring wire thickness than it is in the $K = 1$ region.

Because of the strong dependence of the NSS O.D. on the spring wire thickness, it is important to optimize the spring wire thickness for each set of design parameters that is considered. This approach is taken in establishing the results discussed in the following sections. It is also important to note that the spring wire thickness must be limited to provide an acceptable maximum operating temperature for the spring. The lateral support springs are cooled by means of conduction heat transfer through the small stagnant hydrogen gaps to the lateral support spring capsules, and convection heat transfer from the capsule outer surface to the reflector coolant. Figure 3.1.4-2 shows the maximum operating temperatures of the lateral support springs and capsules as a function of the spring wire thickness. This figure is based on calculations that include the uncertainties in heating rates ($1.75 \times \text{Nominal}$) and stagnant hydrogen gaps (0.008 diametral clearance, spring eccentric in capsule). Considering a temperature limit of 1350°R for the spring as was found necessary to prevent inducing a permanent set in laboratory tests on the NRX-A6 springs, the maximum thickness for the spring wire is approximately 0.2" when the innermost spring coil is located at a radius of 24 inches. This radius is typical for the innermost spring coil with the designs considered in this study. Therefore, in establishing the optimum spring wire thickness, values greater than 0.2 inches need not be considered.

Figure 3.1.4-2 Maximum Temperatures in the Lateral Support Spring and the Aluminum Spring Capsule

3.1.5 Configuration of Aluminum Structure

The effect of two different aluminum structure configurations on the NSS O.D. was determined and is shown in Figure 3.1.5-1. There is an important difference between this figure and Figure 3.1.2-2. Figure 3.1.2-2 shows the NSS O.D. versus "G" breakaway for a constant lateral support spring wire thickness. Figure 3.1.5-1 also shows NSS O.D. versus "G" breakaway, but the spring wire thickness varies along the line and has been optimized for each design point as discussed in 3.1.4. An inflection occurs in the curve for the aluminum structure without ribs and composite fuel elements because the maximum spring wire thickness reaches the limiting value of 0.2 inches. Points beyond the 0.2 inch value marked on this curve correspond to a constant spring wire thickness of 0.2 inches.

For the range of "G" breakaway considered in Figure 3.1.5-1, a cylindrical aluminum structure without ribs results in a NSS OD approximately two inches smaller than that for a ribbed aluminum structure. This difference decreases after the spring wire thickness becomes constant at the limiting value. It also appears that, at "G" breakaway values beyond the range shown on Figure 3.1.5-1, an aluminum structure with ribs would have a smaller NSS OD than one without ribs as was seen in Figure 3.1.2-2.

3.1.6 Fuel Element Matrix Material

The effect of the fuel element matrix material on the NSS OD is also shown on Figure 3.1.5-1. A core consisting of Composite elements results in increased NSS OD relative to that for a core consisting of AXF graphite elements. This results because the increased movable mass for a core consisting of Composite elements requires longer, heavier lateral support springs to provide a specified "G" breakaway capability. It can also be seen from Figure 3.1.5-1 that the difference in NSS OD with Composite versus AXF graphite elements increases with the "G" breakaway level.

To provide an NSS design which is capable of providing a specified "G" requirement with either fuel element matrix material, the NSS OD should be selected from

Figure 3.1.5-1 Effect of Aluminum Structure Configuration, Fuel Element Matrix Material, and Lateral Support "G" Breakaway with Inconel 718 Springs

design studies that apply for Composite elements.

3.1.7 Lateral Support Spring Wire Material

Figures 3.1.5-1 and 3.1.7-1 show the NSS OD versus "G" breakaway for two candidate spring wire materials. Figure 3.1.5-1 considers Inconel 718 as the spring material and the proportional limit was used as the allowable stress since this material is classified as "quasi-brittle." Figure 3.1.7-1 shows the results in the same form for springs made of a material that is classified as "ductile," A-286. The allowable stress values and shear moduli are shown on the figures.

Figure 3.1.7-2 compares the results from Figures 3.1.5-1 and 3.1.7-1 for an aluminum structure without ribs. The decreased allowable stress and increased shear modulus of A-286 relative to Inconel 718 results in increased values of the NSS OD when A-286 is used as the spring material. This difference increases as the "G" breakaway value increases, and is greater with a core made of Composite elements than it is for a core made of AXF graphite elements.

3.1.8 Lateral Support "G" Breakaway Capability

The effect of the "G" breakaway capability of the lateral support system has been discussed indirectly in several of the preceding sections and can be seen in Figures 3.1.4-1, 3.1.5-1, 3.1.7-1, and 3.1.7-2. Figure 3.1.7-2 summarizes the effect of this parameter with the other design parameters at the "best" values established above. The NSS OD is shown to be strongly dependent on the "G" breakaway requirement and the sensitivity of the NSS OD to "G" breakaway is increased with increasing core movable mass (Composite versus AXF graphite elements) and decreasing allowable spring stresses (A-286 versus Inconel 718 spring material).

3.2 SUMMARY OF RESULTS

Table 3.2-1 gives the optimized values for the NSS OD resulting from the study and summarizes the effects of three design parameters. These parameters are fuel

Figure 3.1.7-1 Effect of Aluminum Structure Configuration, Fuel Element Matrix Material, and Lateral Support "G" Breakaway with A-286 Springs

Figure 3.1.7-2 Effect of Lateral Support Spring Wire Material and "G" Breakaway

TABLE 3.2-1 SUMMARY OF OPTIMUM NSS O.D. VALUES

FUEL ELEMENT MATERIAL	SPRING MATERIAL	NSS O.D.		
		0.75G(DYNAMICS)	1.5G(BUNDLING)	2.0G(INC-21 LAUNCH)
AXF GRAPHITE	INCONEL 718 to P.L.	52.10	52.80	53.20
COMPOSITE	INCONEL 718 to P.L.	52.50	53.50	54.60
AXF GRAPHITE	A-286	52.30	53.15	53.65
COMPOSITE	A-286	52.80	54.45	56.50

element matrix material, lateral support spring material, and the "G" breakaway requirement for the lateral support system. The optimized values of the NSS OD vary from a minimum of 52.1 inches for a design providing 0.75 "G" breakaway with AXF fuel elements and Inconel 718 springs to a maximum of 56.5 inches for a design providing 2.0 "G" breakaway with Composite fuel elements and A-286 springs. Increased values of NSS OD result with increased "G" breakaway values, the use of Composite fuel elements rather than AXF graphite fuel elements, and A-286 lateral support springs rather than Inconel 718 springs.

4.0 RECOMMENDATION

The optimized, or minimum, reflector assembly outside diameter recommended as a result of this study is 54.0 inches.

The aluminum reflector structure which evolved as a result of this study is ribless which permits utilization of larger control drums than would be possible with a ribbed structure. The high probability and confidence levels required for achieving the control drum requirement and the large LSS springs for "G" levels dictated the drum size. The control drum size is based upon utilization of control vanes which have a boron loading equivalent to a surface density of 0.100 gram per square centimeter (18 volume per cent). The grafoil insulation lining the inside surface of the ribless aluminum reflector structure is 30 mils thick. This thickness is recommended to provide flexibility to accommodate contingencies in the design of the lateral support and core periphery regions.

5.0 REFERENCES

- A-1 DRM 52691, WANL Presentation of NSS Radial Dimension Optimization Study on June 3, 1970
- A-2 DRM 52692, WANL Presentation of NSS Radial Dimension Optimization Study on June 11, 1970
- 1.0-1 DRM 52465A, Reflector Structural Material Selection (Supplementary Information)
- 2.1.1-1 WANL-TME-2709, Fuel Element Trade Study Order of Preference, No. 769
- 2.1.2-1 DRM 52440A, Core Periphery - Corrosion Resistant, Thermal Design
- 2.1.2-2 DRM 52704, Allowable Radial Outward Heat Flux for Peripheral Fuel Elements, Structural Analysis
- 2.1.3-1 DRM 52533, R-1 Core Radial Expansion of a High Expansion Graphite Core and a Composite Core
- 2.1.3-2 DRM 52473, Lateral Support Radial Space Requirements
- 2.1.3-3 WANL-TME-1219, Full Core Axial Inter-Element Impedance Test
- 2.1.4-1 DRM 52712, Ductile vs. Brittle Stress Limit for Inconel 718 Lateral Support Spring
- 2.1.4-2 Material Properties Used for Lateral Support Spring Analysis in NSS Radial Optimization Study
- 2.1.5-1 DRM 52429, Aluminum Support Cylinder Thickness as a Function of Allowable Stress for an 864 psi Maximum Pressure Drop
- 2.1.5-2 DRM 52530, Aluminum Support Structure (Without Stiffener Ribs) Thickness Required for 864 psi Maximum Pressure Drop
- 2.1.5-3 DRM 52624, Structural Analysis Input: NSS Radial Dimension Optimization Study (For Aluminum Structure Can & Pressure Vessel)
- 2.1.5-4 DRM 52465A, Reflector Structure Material Selection (Supplementary Information)
- 2.1.6-1 DRM 52095, Nuclear Supporting Data for the NSS Radial Dimension Optimization Study
- 2.1.6-2 DRM 52628, Control Drum Bore Liner Thickness and Clearance to Beryllium Reflector for NSS Radial Optimization Study
- 2.1.6-3 DRM 52460, Copper Boron Vs. Aluminum Boron Control Drum Vanes

REFERENCES (Continued)

- 2.1.7-1 DRM 52624, Structural Analysis Input: NSS Radial Dimension Optimization Study (For Aluminum Structure Can & Pressure Vessel)
- 2.1.7-2 DRM 52629, Material Property Input: NSS Radial Dimension Optimization Study (For Aluminum Structure Can & Pressure Vessel)
- 2.1.8-1 DRM 52624, Structural Analysis Input: NSS Radial Dimension Optimization Study (For Aluminum Structure Can & Pressure Vessel)
- 2.2.6-1 DRM 52095, Nuclear Supporting Data for the NSS Radial Dimension Optimization Study
- 2.2.8-1 DRM 51891, Reflector-Pressure Vessel Clearance Gap
- 2.3-1 DRM 52372, Radiation and Shielding Input to the NSS Radial Dimensions Study
- 2.3-2 DRM 52578, Core Periphery Corrosion Resistant and the LSS
- 2.3-3 DRM 52579, Thermal Design Input to the NSS Radial Dimension Optimization Study
- 2.3-4 DRM 52624, Structural Analysis Input: NSS Radial Dimension Optimization Study (For Aluminum Structure Can and Pressure Vessel)
- 2.3-5 DRM 52629, Material Property Input: NSS Radial Dimension Optimization Study (For Aluminum Structure Can and Pressure Vessel)
- 2.3-6 DRM 52095, Nuclear Supporting Data for the NSS Radial Dimension Optimization Study
- 2.3-7 DRM 52901, Geometry Input to the NSS Radial Optimization Study
- 2.3-8 DRM 52625, LSS Structural Input for Radial Optimization Study
- 2.3-9 DRM 52715, Material Properties Used for Lateral Support Spring Analysis (DRM 52625) in NSS Radial Optimization Study
- 2.3-10 DRM 52713, Lateral Support Spring Capsule (Functional Relationship Used in Radial Optimization Code)
- 2.3-11 DRM 52908, Radial Sizing Program (RSP) Description and Users' Guide

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TITLE NSS Radial Dimension Optimization Study	
DOCUMENT NO. WANL-TME-2707		DATE September 1970	
ABSTRACT <p> This report presents a trade study of parameters affecting the outside radial dimension of the reflector assembly, a component of the NERVA Nuclear Subsystem. The purpose of this study is to provide justification of the parameters affecting the radial dimension and to determine the most logical and reasonable combination of component radial dimensions to minimize the reflector assembly outside dimension. </p>			
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