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REFLECTOR-NOZZLE DESIGN TRADE STUDY

TRADE STUDY NO. 780

COPY FOR ANSC

5/22/70

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1.0 INTRODUCTION

The purpose of this trade study is to provide Aerojet Nuclear Systems Company (ANSC) with input for a final trade study which ANSC is to prepare on a nozzle-to-reflector joint. This study, which is the Westinghouse Electric Corporation (WEC) response to TD-70-27 as contained in Change Order W-70-6, is limited to the reflector-nozzle and reflector-pressure vessel interface areas and does not include effects of shortening the nozzle barrel.

This study presents the WEC evaluation of eight nozzle-to-reflector joint concepts. Three of the concepts were prepared by WEC, one was suggested by SNPO, and the other four were prepared by ANSC.

Two of the three WEC concepts deviate considerably from the nozzle-to-reflector joints developed for the NRX-A and XE reactors in the past. The other, which is the reference design shown in Figure 2, is basically the same as that used in the NRX-A6 reactor.

The concept suggested by SNPO (referred to in this report as WEC Concept 4) also deviates from the joints used in past reactors. It combines some of the features in the reference design with a counterflow nozzle barrel and a welded seal arrangement.

The ANSC concepts are all similar to the WEC reference design with the exception that the ANSC concepts include a redundant method for clamping the nozzle-reflector interface joint. The clamping of this joint is accomplished through the nozzle and pressure vessel bolt holes.

There were at least two reactors in the past that were aft supported in a manner similar to the reference design shown in Figure 2. These reactors, which also had a nozzle-reflector interface joint similar to the reference design, were the NRX-A6 and the Phoebus 2A.

The NRX-A6 reflector and core was supported inside the pressure vessel by six standoffs which were fastened to the pressure vessel on the aft end and to the tie bolts

at the reflector. These standoffs, which also clamped the reflector against the nozzle, are replaced in the reference design by 18 attachment bolts as shown in Figure 2. The NRX-A6 nozzle-reflector interface seal was a pressure actuated U-flex seal identical to the reference design. The seal surfaces at the nozzle-reflector interface in the NRX-A6 were titanium and stainless steel, whereas, in the reference design they are aluminum and stainless steel.

The Phoebus 2A reactor was supported in the pressure vessel by 18 support bolts in a manner similar to the reference design. These support bolts, which also clamp the reflector against the nozzle, pass through the nozzle-pressure vessel bolt holes and are threaded into the aft stiffening ring of the reflector. An omega seal was used at the nozzle-reflector interface joint instead of the U-flex seal shown in the reference design. The seal surfaces at this interface in the Phoebus 2A were aluminum and stainless steel, which are identical to the reference design.

All NRX and XE reactors prior to the NRX-A6 were forward supported and contained a graphite inner reflector. The graphite inner reflector was spring loaded against the stainless steel nozzle by a spring-ring arrangement at the forward end. The interface joint was sealed by an E-seal compressed between the nozzle and the inner reflector.

It is evident from the above discussion that the reference design shown in Figure 2, the NRX-A6, and the Phoebus 2A all have similar nozzle-to-reflector joints. The technology gained from the NRX-A6 and the Phoebus 2A is therefore applicable in the evaluation of the eight concepts being presented in this trade study.

2.1 SEAL REQUIREMENTS

The temperature of the coolant flow, as shown in Table 1; for the reflector inlet side of the nozzle-reflector interface seal is 184°R . The temperature in the chamber which is the low pressure side of the seal, see Figure 2, is 4250°R . Since leakage past this seal would reduce the temperature of the gas in the chamber which in turn lowers the specific impulse of the engine, it is desirable to minimize the seal leakage rate. A firm leakage rate has not yet been established between ANSC and WEC, however, for this study a maximum leakage rate of .015 lb/sec was assumed for evaluating the various joint concepts. This value is based on the pressure and flow tests conducted on the nozzle interface seals for the NRX and XE reactors as discussed in TRD-68-190.

2.2 FLOW REQUIREMENTS

The coolant which flows through the nozzle barrel, see Figure 2, enters the reflector inlet near the nozzle-reflector interface joint. It was established that design concepts that increased the pressure drop through the nozzle barrel over 25 psia as compared to the reference design were unacceptable. This was agreed upon by WEC and ANSC as stated in memorandum 7750:L0879.

The state points in Table 1 shall be used to determine if the flow through the nozzle is adequate to cool the nozzle barrel and the reflector.

2.3 STRUCTURAL REQUIREMENTS

Since the entire nuclear subsystem (NSS) is supported by the reflector, the nozzle-reflector interface joint must be capable of supporting the NSS inside the pressure vessel when subjected to the environment specified in the Reflector Assembly Specification No. EC-677559. This specification defines the nuclear, load, and thermal environment for the reflector.

The interface joint must also withstand the forces it encounters as a result of pressure drops between various positions in the NSS during reactor operating conditions. These forces are to be determined from the state points shown in Table 1.

TABLE 1
FULL POWER SOL-MINIMUM STEM FLOW

	<u>Flow lbs/sec</u>	<u>Pressure psia</u>	<u>Temp. °R</u>
*Nozzle Tube Inlet	83.1	1282.4	58.6
*Nozzle Tube Outlet	83.1	1124.3	184.0
*Reflector Inlet	75.3	1124.3	184.0
Core Inlet	91.2	623.2	267.0
*Core Outlet	91.2	450.0	4250.0
Extension Shield Inlet	48.1	1057.0	277.0
Extension Shield Outlet	48.1	1035.0	280.0
Central Shield Inlet (Forward)	91.2	654.0	262.0
Central Shield Inlet (Aft)	91.2	642.0	262.0
Core Support Plate Inlet	91.2	636.0	265.0
Core Inlet	91.2	624.0	270.0
*Chamber	91.2	450.0	4250.0
*Turbine Discharge at Dome	91.2	1034.0	280.0

*Statepoints that directly influence the nozzle-reflector interface joint evaluation.

2.4 ASSEMBLY REQUIREMENTS

The assembly sequence of the nozzle-to-reflector joint is governed by the assembly sequence of the overall NSS, pressure vessel and nozzle.

As shown in Figure 1, the first step is to assemble the entire NSS. The NSS is then placed in the pressure vessel cylinder and fastened to the aft end with the attachment bolts as shown in the reference design, Figure 2. The pressure vessel closure, in addition to other accessories, are then assembled and the unit is ready for shipment. The unit, which is now called a Nuclear Subsystem Module (NSSM), is then shipped from WEC to the Test Site. The nozzle, see Figure 1A, is then installed at the Site after the NSSM is installed on the test car.

It can be seen, since the nozzle is one of the last items to be installed, that it would be desirable to have a nozzle-to-reflector joint that could be readily assembled with very little final adjustment and risk of damage to the NSSM.

Figure 1

Figure 1A. Install Nozzle to NSSM

3.0 DESCRIPTION OF DESIGN APPROACHES

3.1 WEC CONCEPT 1 (REFERENCE DESIGN)

3.1.1 General Description of Concept 1

This design concept, see Figure 2, is similar to the nozzle-to-reflector joint developed for the NRX-A6 reactor.

In this concept the entire nuclear subsystem (NSS) is supported by 18 attachment bolts which are threaded into the reflector structure on one end and fastened to the pressure vessel on the aft end. The forces due to the axial pressure drop across the NSS during operation are transmitted from the reflector structure, through the aft support ring, to the nozzle barrel.

The nozzle coolant flows forward, in this concept, along the inner face of the nozzle barrel to the aft support ring joint and then radially outward into the reflector inlet. The pressure drop in the nozzle barrel is minimized by having only one right angle turn in the flow path.

In this concept, it is necessary to have two seal joints between the reflector structure and the nozzle. The bolted joint between the reflector structure and the aft support ring is sealed by a metallic O-ring seal. A metal U-flex seal is used between the aft support ring and the nozzle. During reactor operation, the compressive load on both seals is increased due to a pressure differential across the NSS. The nozzle-pressure vessel joint is sealed in the conventional manner, with an omega seal at the interface and gasket seals at the nozzle bolt locations.

3.2 WEC CONCEPT 2 (COUNTERFLOW NOZZLE BARREL DESIGN)

3.2.1 General Description of Concept 2

The approach in this concept, see Figure 3, was to eliminate the attachment bolts and fasten the reflector support structure directly to the pressure vessel. The nozzle barrel, as shown, supports no compressive load since the load is transmitted directly to the

WEC CONCEPT 1
(REFERENCE DESIGN)

FIGURE 2

WEC CONCEPT 2

(COUNTERFLOW NOZZLE BARREL)

FIGURE 3

pressure vessel. The primary function of the nozzle barrel is to provide a flow path for coolant to cool the inner face of the reflector structure.

The flow path, as can be seen in Figure 3, is forward along the inner face of the nozzle, then aft along the outer face of the nozzle barrel to the nozzle flange where the direction is again reversed. Additional attention will have to be given to the design of the nozzle to minimize the pressure drops due to the flow reversals.

The joint between the reflector structure and the pressure vessel is sealed by an omega seal. This joint is held firmly together during handling and operation by the bolts which are inserted through the nozzle flange bolt holes. During operation, the joint clamp load is increased by the pressure differential across the NSS. Two omega seals are required to seal the joint between the pressure vessel and the nozzle. The nozzle flange bolt holes are sealed in a conventional manner with gasket seals under the bolt heads.

3.3 WEC CONCEPT 3 (UNI-DIRECTIONAL FLOW DESIGN)

3.3.1 General Description of Concept 3

As in the WEC Concept 2, the reflector structure illustrated in Figure 4 is fastened directly to the pressure vessel. It can be seen that the load path and the bolted joint arrangements are also the same. The unique difference in this concept is that the nozzle barrel has been eliminated.

The flow in this concept is forward along the inner face of the nozzle, through the pressure vessel flange, and into the reflector support structure. The flow channels through the pressure vessel flange and support structure are welded tube configurations similar to the flow channels at the inner surface of the nozzle.

The joints at the reflector structure-pressure vessel interface and nozzle-pressure vessel interface are sealed in the same manner as that described in WEC Concept 2.

WEC CONCEPT 3
(UNI-DIRECTIONAL FLOW)

FIGURE 4

WEC CONCEPT 4
 (WELDED CORRUGATED CYLINDER)

FIGURE 5

3.4 WEC CONCEPT 4 (WELDED CORRUGATED CYLINDER DESIGN)

3.4.1 General Description of Concept 4

This concept combines several features of the concepts just described with a redundant method for sealing the reflector structure-nozzle interface joint.

The method for supporting the NSS inside the pressure vessel is the same as that described in WEC Concept 1.

The coolant flow path, as can be seen in Figure 5, is similar to that described in WEC Concept 2. The major difference in this concept is that the flow is dumped directly into the reflector inlet from the pressure vessel flow channels.

The nozzle-pressure vessel interface joint is sealed in the same manner as WEC Concepts 2 and 3. A U-flex seal is utilized at the reflector structure-nozzle interface joint as a backup seal. The primary seal at this joint is the corrugated cylinder which is welded to the aft support ring of the reflector and the pressure vessel.

3.5 ANSC CONCEPT 1 (MARMAN CLAMP-OMEGA SEAL)

3.5.1 General Description of Concept 1

The primary support for the NSS in this concept, Figure 6, is the same as that described in WEC Concept 1. In addition to this, a marman type clamp is utilized at the reflector structure-nozzle interface joint to provide a redundant method for clamping the joint. The segmented marman type clamp is activated externally through the pressure vessel bolt holes by means of a flexible drive cable. The three segment marman clamp is guided axially by slots and the existing attachment bolts. During assembly the marman clamp is positioned and connected to three flexural cables inserted through the pressure vessel bolt holes prior to nozzle installation. Once the nozzle is secured in place, the flexural cable is driven by an external power tool and secures the marman clamp. This tightening of the marman type clamp is accomplished by means of a worm gear drive that turns twin clamp screws at three locations.

FIGURE 6

The flow path in this concept is approximately the same as that described in WEC Concept 1. The only exception is that the flow leaves the nozzle barrel at an angle which allows it to by-pass the clamp.

An omega seal is used at the reflector structure-nozzle interface joint in place of the U-flex seal shown in WEC Concept 1. The seals at the nozzle-pressure vessel interface joint are the same as that described in WEC Concept 1.

3.6 ANSC CONCEPT 2 (MARMAN CLAMP-CONICAL SEAL)

3.6.1 General Description of Concept 2

This concept, see Figure 6, is the same as ANSC Concept 1 except that a conical seal is used in place of the omega seal at the reflector structure-nozzle interface joint.

3.7 ANSC CONCEPT 3 (BOLTED JOINT-EXPANDABLE SEAL)

3.7.1 General Descriptions of Concept 3

The NSS in this concept is supported by 18 attachment bolts as described in WEC Concept 1. The joint at the reflector structure-nozzle interface is sealed by utilizing an expandable seal and ring configuration as shown in Figure 7. The expandable seal is welded to the support structure and the ring. The ring in turn is bolted to the nozzle barrel and compresses an omega seal which seals the ring-nozzle joint. The captive bolts in the ring are tightened through the nozzle hold-down bolt holes.

The flow path in this concept is the same as that described in WEC Concept 1 with the exception that the flow leaves the nozzle at an angle which allows it to bypass the bolt heads.

ANSC CONCEPT 3
 (BOLTED JOINT-EXPANDABLE SEAL)

FIGURE 7

3.8 ANSC CONCEPT 4 (BOLTED JOINT-OMEGA SEAL)

3.8.1 General Description of Concept 4

This concept, as shown in Figure 8, is approximately the same as ANSC Concept 3. The major difference is that the bolts at the reflector structure-nozzle interface joint are threaded directly into the structure instead of the ring. To accomplish this, it is necessary to machine the bolt holes at the nozzle-pressure vessel interface at an angle.

(CORE)

ANSC CONCEPT 4
 (BOLTED JOINT-OMEGA SEAL)

FIGURE 8

COMPARISON MATRIX OUTLINE

Functional & Technical Design Requirements

WEC Concepts

ANSC Concepts

RELIABILITY

Seals

Reflector Attachment

Nozzle Flow

Reflector Flow

Nozzle Attachment

PERFORMANCE

(Structural)

Thermal & Mechanical Distortion

Structural Integrity

(Thermal)

Seal Leakage

Pressure Drop Through Transition

Nozzle Maximum Temperature

Aluminum Structure Maximum Temperature

(Nuclear)

Neutronic Effects

WEIGHT

Transition Joint ΔW (Based on Reference)

DEVELOPMENT

NRX-A Experience

Fabrication Feasibility

Assembly Techniques

Shipping Techniques

SCHEDULE

Nozzle Configuration Development

Aluminum Structure Development

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	Westinghouse Astronuclear Laboratory	DRM TYPE (13) Analysis	
	CODE IDENT NO. 14683	DEPARTMENT (13) Structural	
SHEET 1 OF 9		DATE (6) 5/22/70	REACTOR NERVA

SUBJECT (120)	STRUCTURAL DESIGN INPUT TO THE REFLECTOR-NOZZLE DESIGN TRADE STUDY
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PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM	
1.	59						1.	2.
2.							3.	4.
3.							5.	6.

DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)				
1.DRM 52632	2.WANL-TME-1654	3.SI-AEP-1170	4.WANL-TMI-1974	5.DRM 51207 D
6. SNPO-C-1	7.DRM 51201A	8.ROARK	9.	10. 1961

1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)

1. PURPOSE:
Present the preliminary structural analyses that have been performed on the various components of the Reflector-Nozzle Design concepts.

2.0 STRUCTURAL ANALYSIS OF REFLECTOR-NOZZLE DESIGN CONCEPTS

2.1 WEC CONCEPT 1 (DWG 982D521)

2.1.1 Nozzle Interface Load Estimates
A preliminary analysis (documented on Reference 1) was performed to calculate the standoff preload required to react the estimated dynamic loads to insure that separation does not occur between the nozzle and reflector. The effect of the reactor operating pressure loads on the nozzle interface load was also considered. Based on the assumptions of the analysis (refer to Reference 1), the required standoff preload for the launch condition is 16.22 G's or 244,000 lbs, and the required standoff preload for a Test Cell C firing is 7.8 G's or 117,000 lbs. Considering 18 standoffs, the minimum required standoff diameter is 0.45 in. for launch and 0.325 in. for Test Cell C firing. Both of these diameters are reasonable design values.

Although this analysis is preliminary in nature, it demonstrates the fact that separation between the nozzle and reflector does not occur if the standoffs are preloaded to react the maximum dynamic loads.

APPROVALS	INFORMATION CATEGORY	SECURITY CLASS
PREPARED BY <u>R. S. Joseph</u> DATE <u>5/22/70</u>	CLASSIFICATION	
APPROVED BY _____ DATE _____	AUTHORIZED CLASSIFIER _____ DATE _____	

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2.1.1 Nozzle Interface Load Estimates (continued)

During reactor operation the net effect of the reactor pressure loads is to significantly increase the nozzle load.

2.1.2 Nozzle Interface Seal Analysis

This seal is similar to the NRX-A6 nozzle seal, but for R-1 application the ΔP across this seal is four to five times greater than that of the NRX-A6. The results of the NRX-A6 seal analysis (Reference 2) were used to predict the design parameters of the R-1 seal. A discussion of the analysis follows.

2.1.2.1 Assumptions:

- (1) ΔP across seal is 852 psi per Reference 3.
- (2) Seal material is Inconel 718 which is classified as a quasi-brittle material by Materials Department.
- (3) Nominal $K_{IC} = 25 \text{ KSI} \sqrt{\text{in.}}$
- (4) A 0.002 in. surface crack is assumed to determine the SIL based on fracture mechanics
- (5) If SIL for Inconel 718 based on fracture mechanics is higher than the SIL based on ductile analysis, use ductile limits.

2.1.2.2 Analysis

The following fracture mechanics model (Reference 4) is used to determine the SIL:

$$SIL = \sigma = \frac{K_{IC} d^{3/2}}{h^2 G(a/h)}$$

$$K_{IC} = 0.8 (\bar{\sigma} - 2.33\sigma)$$

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The following table shows how the SIL varies as a function of h for the assumed crack depth of $a = 0.002$ in:

a (in)	h (in)	SIL (psi)
0.002	0.020	189,000
0.002	0.035	196,000
0.002	0.050	208,000

To be conservative the $SIL = 189,000$ psi is used as the fracture mechanics allowable.

The 2.33 sigma minimum yield strength of Inconel 718 (Reference 5) is 150,000 psi at 535°R. Therefore, the ductile limits for Inconel 718 are:

Primary bending - $SIL = \sigma_y = 150,000$ psi

Primary & Secondary - $SIL = 2\sigma_y = 300,000$ psi

Therefore, the material allowables used in this analysis are;

Primary bending - $SIL = 150,000$ psi

Primary & Secondary - $SIL = 189,000$ psi

The nozzle seal can be idealized by using the following two beam models:

Assembly stress due to preload deflection

$$\sigma \sim \frac{P l}{t^2}$$

EQ (1)

Stress due to pressure drop

$$\sigma \sim \frac{\Delta P l^2}{t^2}$$

EQ (2)

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Using the NRX - A6 seal dimensions, calculated stresses, and Equations (1) and (2), the stresses in the R-1 seal can be predicted as follows:

Maximum Assembly Stress

$$\sigma_1 = \sigma_{AG1} K_1 \frac{S}{S_{AG}} \frac{t}{t_{AG}} \frac{L_{AG}^2}{L^2} \quad \text{EQ (3)}$$

Maximum Operating Stress due to Preload Deflection Plus Pressure

$$\sigma_2 = \sigma_{AG2} K_1 \frac{S}{S_{AG}} \frac{t}{t_{AG}} \frac{L_{AG}^2}{L^2} + \sigma_{AG3} K_2 \frac{\Delta P}{\Delta P_{AG}} \frac{L^2}{L_{AG}^2} \frac{t_{AG}^2}{t^2} \quad \text{EQ (4)}$$

Where:

$$\sigma_{AG1} = -143,000 \text{ PSI}$$

$$\sigma_{AG2} = 67,200 \text{ PSI}$$

$$\sigma_{AG3} = 53,400 \text{ PSI}$$

$$\Delta P_{AG} = 250 \text{ PSI}$$

$$S_{AG} = 0.040 \text{ IN.}$$

$$t_{AG} = 0.020 \text{ IN.}$$

$$L_{AG} = 0.56 \text{ IN.}$$

Substituting the above values into EQ (3) and EQ (4)

$$\sigma_1 = 5.8 \times 10^7 \frac{St}{L^2} \quad \text{EQ (5)}$$

$$\sigma_2 = 2.72 \times 10^7 \frac{St}{L^2} + 0.289 \frac{\Delta P L^2}{t^2} \quad \text{EQ (6)}$$

In addition the stress due to pressure in EQ (6) must satisfy the primary bending stress requirement.

$$\therefore 0.289 \frac{\Delta P L^2}{t^2} \leq 150,000 \text{ PSI} \quad \text{EQ (7)}$$

$$\text{AND } \sigma_1 = \sigma_2 \leq 159,000 \text{ PSI}$$

Equations (5), (6) and (7) must be solved by trial and error, and many solutions are possible depending on the preload deflection.

2.1.2.3 Results

For a $\Delta P = 852$ and a preload deflection of $\delta = 0.030$ in. per leg (or total of 0.060 in.) the following values satisfy Equations (5), (6) and (7):

$$t = 0.035 \text{ in.}$$

$$l = 0.85 \text{ in.}$$

Based on this preliminary sizing analysis, it appears that a nozzle seal can be designed to carry the required pressure load.

2.1.3 Estimated Thermal Distortions of Nozzle Flange

Figure 1 shows the estimated axial gap between the aft support ring and nozzle flange versus angular position. These gaps are based entirely on the circumferential variation in temperature in the nozzle flange and they should represent the maximum envelope.

2.1.4 Recommendations

From a structural viewpoint one "O" ring seal and a bolted joint can be eliminated from this concept if the aft support ring and reflector barrel are incorporated into one piece.

2.2 WEC CONCEPT 2 (DWG 982D250)

Basically this concept is an interface joint problem between WEC and ANSC. Two of the "O" ring seals are between the nozzle flange and pressure vessel flange which are entirely ANSC components. In order to predict any meaningful gaps at the "O" ring seal locations, a finite element model using detailed thermal distributions from WEC and ANSC is required. The sealing characteristics of the "O" ring seal itself must be determined by component test.

2.3 WEC CONCEPT 3 (DWG 982D252)

Same as 2.2.

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2.4 WEC CONCEPT 4 (DWG 982D253)

2.4.1. Same as 2.1.1, 2.1.2, 2.1.3, and 2.1.4

2.4.2 Corrugated Seal Analysis.

This seal is a part of a redundant sealing system consisting of this corrugated seal and the nozzle interface seal discussed in Section 2.1.2. Either of these two seals should be capable of carrying the required ΔP .

In order for the corrugated seal to satisfy the structural requirements per Reference 6, the diameter of the seal must be sized such that a small radial displacement due to pressure is acceptable before the seal seats against the nozzle barrel. (Similar to a balloon inside a can.) The other functional requirement of this seal is that it has a sufficient number of corrugation to satisfy the specified axial displacement. A discussion of the preliminary sizing analysis follows:

2.4.2.1 Assumptions

- (1) Seal material is 6061-T6
- (2) Room temperature material properties
- (3) Maximum axial deflection is 0.5 in. (0.2 in. due to preload + 0.3 in. allowed for differential contraction)
- (4) Mean radius of seal 21.65 in.

2.4.2.2 Analysis

The following equations were obtained from Reference 8:

$$S = \frac{1.813 P b m (1 - \nu^2)^{1/2}}{\pi E t^2} \quad (\text{Deflection}) \quad \text{EQ (8)}$$

$$S' = \frac{1.63 P \left(\frac{Rb}{t}\right)^{1/3}}{2\pi t \sqrt{1 - \nu^2}} \quad (\text{Bending Stress}) \quad \text{EQ (9)}$$

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n = number of semicircular corrugations

Substituting Equation (8) into Equation (9) and solving for n:

$$n = \frac{0.45}{(1-\mu^2)^{3/2}} \left(\frac{E}{SIL} \right)^{1/3} \frac{SE}{SIL} \quad \text{EQ (10)}$$

Where: $E = 9.8 \times 10^6 \text{ PSI}$
 $\mu = .33$
 $SIL = 60,150 \text{ PSI}$
 $a = 21.65 \text{ IN.}$
 $\delta = 0.5 \text{ IN.}$

Assume: $t = 0.020 \text{ IN.}$ $b = 0.12 \text{ IN.}$

2.4.2.3 Results

For the specified parameters in Section 2.4.2.2 the required number of semicircular corrugations is 6 for 0.5 in. deflection. Therefore, this seal can be designed as a thin shell with 6 semicircular corrugations. There are an infinite number of solutions to Equation (10) which depend on the assumed variables.

2.5 ANSC CONCEPT 1 (DWG 1137995)

This concept is similar to WEC Concept I except for the Marmon clamp and "K" seal. The Marmon clamp and "K" seal can be selected from the manufacturer's data for the required ΔP .

2.6 ANSC CONCEPT 2 (DWG 1137995)

This concept is basically the same as ANSC Concept I except for the addition of a shear lip on the nozzle flange and a standard Marmon clamp seal which replaces the "K" seal.

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2.7 ANSC CONCEPT 3 (DWG 1138044)

This concept allows for relative axial displacement between the nozzle and reflector. As stated in Section 2.1.1 separation does not occur if the standoffs are properly preloaded; therefore, this axial displacement provision does not appear to be needed. The disadvantages of this concept are that two seals are required to seal the joint and that the welded tip on the "omega" type seal may cause stress problems.

2.8 ANSC CONCEPT 4 (DWG 1138044)

This concept is basically the same as ANSC Concept 2 except for the bolted joint which replaces the Marmon clamp and "K" seal which replaces the flat seal.

3.0 CONCLUSIONS:

Not applicable. The individual conclusions are given with the discussion of each Concept.

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FIGURE 1. ESTIMATED AXIAL GAP BETWEEN AFT SUPPORT RING AND NOZZLE FLANGE VERSUS ANGULAR POSITION

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REV (1)

Westinghouse Astronuclear Laboratory

CODE IDENT NO. 14683

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DRM TYPE (13)

ANALYSIS

DEPARTMENT (13)

STRUCTURAL

SUBJECT (120)

NOZZLE INTERFACE LOAD ESTIMATES FOR REFLECTOR -
NOZZLE DESIGN TRADE STUDY

DATE (6)

5/21/70

REACTOR

NERVA

PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM	
1.	59						1.	2.
2.							3.	4.
3.							5.	6.

DOCUMENT REFERENCES

(DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)

1. DWG 940J385	2. SI: AEP:1170	3. DRM 51238	4.	5.
6.	7.	8.	9.	10. 2000

1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)

1.0 PURPOSE:

Calculate the standoff preload required to react the estimated dynamic loads to insure that no separation occurs between the nozzle and reflector. Consider what effect the reactor pressure loads have on the nozzle interface load during a reactor test.

2.0 ASSUMPTIONS/METHODS

2.1 Dynamic loads

2.1.1 Dynamic loads at engine/stage interface during launch

 ± 2.25 G Longitudinal ± 1.50 G Lateral

2.1.2 Estimated Design Loads (Considered limit loads in this analysis).

2.1.2.1 Launch condition (Reactor not operating)

Apply a dynamic magnification factor of 2.0 to loads given in 2.1.1; therefore, ± 4.5 G Longitudinal ± 3.0 G Lateral

2.1.2.2 Test Cell C firing (Reactor up-firing)

 ± 1.5 G Longitudinal ± 1.25 G Lateral

APPROVALS

R S Joseph 5/21/70
PREPARED BY DATEB J Down 5-21-70
APPROVED BY DATE

INFORMATION CATEGORY

unclassified
CLASSIFICATION
B J Down 5-21-70
AUTHORIZED CLASSIFIER DATE

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2.2 Estimated reactor parameters based on Reference 1.

2.2.1 Weight of NSS (W) = 15,000 lbs.

2.2.2. Distance from aft support ring/nozzle interface
to center of gravity of NSS (d) = 45 in.

2.2.3 Mean radius of aft support ring (R) = 21.2 in.

2.2.4 Area between pressure vessel I.D. and nozzle seal (A_1) = 870 in.²

2.2.5 Area within diameter of nozzle seal (A_2) = 1410 in.²

2.3 Analysis based on state points per Reference 2.

2.4 Standoff Sizing.

2.4.1 Eighteen standoffs of A-286 material.

2.4.2 Room temperature material strength per Reference 3
(Conservative since operating temperature of standoffs is below
R.T. and strength is higher in cryogenic range.)

2.4.3 Variation of standoff load = 0 since dynamic loads are assumed
to be limit loads by 2.1.2.

2.4.4 Margin of safety = 0

2.4.5 For launch condition no additional loads on standoffs due to
differential thermal contraction or other imposed mechanical loads
are considered.

2.4.6 For Test Cell C firing a 10 percent increase in standoff load due
to differential thermal contraction is assumed per RATS predictions.

2.5 METHODS

2.5.1 Hand calculations

2.5.2 Equations and model discussed in Analysis section.

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3.0 CONCLUSIONS:

3.1 Launch condition

3.1.1 The required standoff preload to prevent reflector - nozzle separation is 16.22 G's or 244,000 lbs.

3.1.2 Based on assumptions of this analysis the minimum required standoff diameter is 0.45 in.

3.2 Test Cell C firing

3.2.1 The required standoff preload to prevent reflector - nozzle separation is 7.8 G's or 117,000 lbs.

3.2.2 Based on assumptions of this analysis the minimum required standoff diameter is 0.325 in.

3.2.3 During reactor operation the net effect of the reactor pressure loads is to increase the nozzle load.

3.3 This analysis should be regarded as preliminary in nature; however, it demonstrates the fact that separation between the nozzle and reflector does not occur if the standoffs are preloaded to react the maximum dynamic loads.

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ANALYSIS

A-1.0 MODEL TO CALCULATE STANDOFF PRELOAD

WHERE G_1 = LATERAL DYNAMIC G LOAD G_2 = LONGITUDINAL G LOAD $W = IG$ = STATIC WEIGHT OF N.S.S.
(POSITIVE IN DIRECTION SHOWN) a = DISTANCE FROM OET SUPPORT RING/NOZZLE
INTERFACE TO C.G. OF N.S.S. R = MEAN RADIUS OF OET SUPPORT RING P = STANDOFF PRELOAD

BASIC RELATIONS :

$$w_1 = w_2 + w_3$$

$$w_1 = \frac{P}{2\pi R} = \text{STANDOFF PRELOAD (\#/IN)}$$

$$w_2 = \frac{(G_2 - W)}{2\pi R} = \text{NET LONGITUDINAL G LOAD DUE TO AXIAL LOADS (\#/IN)}$$

$$w_3 = \frac{M}{\pi R^2} = \frac{G_1 d}{\pi R^2} = \text{ADDITIONAL LONGITUDINAL G LOAD DUE TO LATERAL LOAD}$$

$$\frac{P}{2\pi R} = \frac{G_2 - W}{2\pi R} + \frac{G_1 d}{\pi R^2}$$

THE REQUIRED PRELOAD IS

$$P = (G_2 - W) + \frac{2G_1 d}{R} \quad \text{EQ. (1)}$$

A-2.0 LAUNCH CONDITION

AS STATED IN ASSUMPTIONS (2.0)

$$G_1 = 3.0G$$

$$G_2 = 4.5G$$

$$W = 1G$$

$$d = 45.0 \text{ IN.}$$

$$R = 21.2 \text{ IN.}$$

SUBSTITUTE ABOVE VALUES INTO EQ. (1)

$$P = (4.5G - 1.0G) + \frac{2(3.0G)(45)}{21.2}$$

$$P = 16.22 G \text{ L}$$

BUT $1G = W = 15,000 \text{ LB.}$

OR

$$P = 244,000 \text{ LB}$$

CALCULATE STANDOFF DIAMETERS TO REDCT P

$$\sigma = \frac{F}{A} = \frac{P/8}{\pi D^2/4} = \frac{2P}{9\pi D^2}$$

$$\therefore D = \sqrt{\frac{2P}{9\pi\sigma}}$$

DIRECT STRESS ALLOWABLE (DRM 51238)

$$SIL = .85 \sigma_y(\text{MIN}) = .85(117,000 - 2.33(6000))$$

$$SIL = .85(103,000) = 87,500 \text{ PSI}$$

$$D = \sqrt{\frac{2(244,000)}{9\pi(87,500)}} \approx 0.45 \text{ IN.}$$

THE MINIMUM STANDOFF DIAMETER REQUIRED FOR THE LAUNCH CONDITION

$$D = 0.45 \text{ IN.} \quad \text{BASED ON (1) MS=0}$$

(2) LOAD VARIATION = 0

A-3.0 TEST CELL C FIRING (UP-FIRING ASSUMED)

AS STATED IN ASSUMPTIONS (2.0)

$$G_1 = 1.25 G$$

$$G_2 = 1.5 G$$

$$W = -1G \quad (\text{SINCE STANDOFFS MUST REDCT WEIGHT OF REDCTOR})$$

$$d = 45.0 \text{ IN.}$$

$$R = 21.2 \text{ IN.}$$

SUBSTITUTE ABOVE VALUES INTO EQ. (1)

$$P = (1.5G + 1.0G) + \frac{2(1.25G)(45)}{21.2} = 7.8G$$

$$P = 7.8G' \Delta$$

$$\text{BUT } 1G = W = 15,000 \text{ LB}$$

$$P = 117,000 \text{ LB}$$

CALCULATE STANDOFF DIAMETERS TO REDCT P

$$D = \sqrt{\frac{2P'}{9\pi\tau}}$$

WHERE $P' = 1.1P$ (ALLOWING FOR 10% INCREASE
IN LOAD DUE TO DIFFERENTIAL
CONTRACTION)

$$D = \sqrt{\frac{2(1.1)(117,000)}{9\pi(87,500)}} \cong 0.325 \text{ IN.} \dots$$

THE MINIMUM STANDOFF DIAMETER REQUIRED FOR
TEST CELL C FIRING

$$D = 0.325 \text{ IN.}$$

BASED ON (1) M.S. = 0

(2) LOAD VARIATION = 0

A-4.0 REFLECTOR/NOZZLE INTERFACE LOAD DUE TO
REACTOR PRESSURE LOADS.

THE NOZZLE LOAD CONSISTS OF SEVERAL COMPONENTS

$$P_{\text{NOZZLE}} = P_{\text{STANDOFFS}} - P_{\text{G-LOADS}} - \Delta P_1 A_1 + \Delta P_2 A_2$$

EQ. (2)

WHERE $P_{\text{NOZZLE}} = \text{NOZZLE LOAD}$

$P_{\text{STANDOFF}} = \text{STANDOFF PRELOAD}$

$P_{\text{G-LOAD}} = \text{DYNAMIC LOADS}$

$\Delta P_1 = \text{AXIAL } \Delta P \text{ (REFLECTOR INLET TO DOME)}$

$A_1 = \text{AREA BETWEEN P.V. AND NOZZLE SEAL}$

$\Delta P_2 = \text{AXIAL } \Delta P \text{ (DOME TO NOZZLE CHAMBER)}$

$A_2 = \text{AREA WITHIN DIAMETER OF NOZZLE SEAL}$

IN SECTION A-3.0 EQ. (1) WAS USED TO BALANCE THE DYNAMIC LOADS WITH THE STANDOFF PRELOAD.

$$\therefore P_{\text{STANDOFF}} = P_{\text{G-LOAD}}$$

THEN EQ. (2) REDUCES TO

$$P_{\text{NOZZLE}} = -\Delta P_1 A_1 + \Delta P_2 A_2$$

FOR SEPARATION TO OCCUR, $P_{\text{NOZZLE}} < 0$

WHICH MEANS $-\Delta P_1 A_1 + \Delta P_2 A_2 < 0$

OR

$$\boxed{\frac{\Delta P_1}{\Delta P_2} > \frac{A_2}{A_1}}$$

EQ. (3)

$$A_1 = 870 \text{ IN}^2 \quad (2.2.4)$$

$$A_2 = 1410 \text{ IN}^2 \quad (2.2.5)$$

REFERENCE : SI: AEP: 1170

REFLECTOR INLET

P
1211 PSIATURBINE INLET LINE
AT DOME

1126 PSIA

CHAMBER

450 PSIA

$$\therefore \Delta P_1 = (1211 - 1126) = \underline{85} \text{ PSI}$$

$$\Delta P_2 = (1126 - 450) = \underline{676} \text{ PSI}$$

SUBSTITUTE A_1 AND A_2 INTO EQ. (3)

$$\frac{\Delta P_1}{\Delta P_2} > \frac{1410}{870}$$

$$\therefore \boxed{\frac{\Delta P_1}{\Delta P_2} > 1.62} \quad \text{FOR SEPARATION TO OCCUR.}$$

IF WE ASSUME $\Delta P_2 = 676$ (DOWNWARD ACTING PRESSURE),
THEN ΔP_1 MUST BE $> 1.62(676) > \underline{1090} \text{ PSI}$ IN
ORDER TO GET SEPARATION.

BUT ACCORDING TO SI: AEP: 1170 $\Delta P_1 = \underline{85} \text{ PSI}$ (UPWARD
ACTING PRESSURE)

THEREFORE, DURING NOMDL OPERATION THE REDUCTOR
PRESSURE LOADS VERY DEFINITELY INCREASE (AND
NOT DECREASE) THE NOZZLE INTERFACE LOAD.

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SUBJECT (120) <div style="text-align: center;">Thermal Analysis for Reflector-Nozzle Design Trade Study</div>						DRM TYPE (13) DEPARTMENT (13) Thermal Design			
DATE (6) 5/22/70		REACTOR R-1							

PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM	
1.							1.	2.
2.							3.	4.
3.							5.	6.

DOCUMENT REFERENCES

(DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)

1.	2.	3.	4.	5.
6.	7.	8.	9.	10.

1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)

PURPOSE:

To provide thermal design input to the reflector-nozzle design trade study.

ASSUMPTIONS/METHODS:

Given in the following discussion sections.

CONCLUSIONS:

The attached discussion sections represent Thermal Design's input to the trade study.

TO BE COMPLETED

APPROVALS <div style="text-align: center;">M. L. Travis</div>		INFORMATION CATEGORY <div style="text-align: center;"><i>Unclassified</i></div>		SECURITY CLASS <div style="text-align: center; font-weight: bold;">UNCLASSIFIED</div>	
PREPARED BY	DATE	CLASSIFICATION		AUTHORIZED CLASSIFIER	DATE
				<i>[Signature]</i>	5/23/70

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1.0 INTRODUCTION

The relative radial leakage, pressure drop, and temperature effects were considered for each of eight reflector-nozzle interface design concepts. Radial leakage into the nozzle chamber was estimated for the reference design by considering the distortions at the sealing interfaces and previous test data on NRX type seals. The pressure drop from a point in the nozzle tube where the tube is parallel to the NSS axis to the reflector inlet plenum was estimated for the various flow channel geometries in the concepts. Increased pressure drop in this region will cause increased pump discharge pressure and the associated system effects. Temperatures were calculated in certain areas to establish the feasibility of the concept relative to material temperature limits, and to support the structural design effort.

2.0 THERMAL AND HYDRAULIC ANALYSIS OF REFLECTOR-NOZZLE DESIGN ALTERNATES

2.1 WEC CONCEPT 1 (DWG. NO. 982D251)

2.1.1 Radial Leakage Effects

An allowable leakage must be determined to establish a criterion by which the eight reflector-nozzle design concepts can be judged. If there is leakage between the reflector inlet plenum and the nozzle chamber, a performance penalty results due to either the reduced specific impulse (if maximum fuel temperature is fixed) or increased maximum fuel temperature (if chamber conditions are fixed). Figure 1 shows the effect of leakage on the core exit temperature. The relationship between these factors is virtually linear at small leakage rates and the slope is approximately $40^{\circ}\text{R}/(\text{lb}/\text{sec})$. Considering the effects that increased maximum fuel temperature has on the fuel development effort, an increase of 4°R on the core exit temperature was selected as a reasonable criteria for setting an allowable leakage. Figure 1 shows that the leakage for a 4°R increase in core exit temperature is 0.1 lb/sec. This value will be used as the allowable value for all design concepts.

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In the reference design, sealing may be provided by two means, either of which may provide the primary sealing. The mating surface between the aft support ring and the nozzle flange may be the primary seal, or the pressure actuated "U" seal may be primary.

In considering the pressure actuated "U"-seal, laboratory test data from the NRX-A6 seals can be used. A plot of the range of this data is shown in Figure 2. The tests were only run to a pressure drop of 300 psig so the results had to be extrapolated from this pressure to the NERVA design ΔP of 750 psig.

In evaluating Figure 2 three things must be considered, (1) The seals used in the NRX-A6 reflector were designed for lower pressure loads than the seals required for NERVA NSS and, therefore, were more flexible. This would permit them to seat much better than the stiffer seals required now. (2) The tests were done at ambient temperatures so evaluation of Figure 2 must account for density changes in the hydrogen. (3) The extrapolated lines in Figure 2 are based on the fact that pressure drop is proportional to flow rate squared. A conservatively large estimate of the leakage flow was made by assuming that at 300 psig the geometry becomes constant and, because this makes the flow area constant, the leakage increases as the pressure drop increases. The maximum leakage from the data extrapolation in Figure 2 is .035 lb/sec for a ΔP of 750 psi (after a correction for fluid density effects). At this leakage a penalty of 1.4°R on the exit temperature of the core results.

The other possible primary seal is the mating surfaces between the nozzle flange and aft support ring. The primary reactor axial load is transmitted through this joint so it could be a good seal. Leakage can occur because of surface roughness and not quite flat surfaces as well as thermal distortions. The temperature distribution in the nozzle flange has been estimated and input to Structural Design for calculation of distortions. These temperatures are summarized in Figure 3. This curve is based on NRX-A6 power test data for the azimuthal

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temperature distribution in the reflector inlet plenum. Superimposed on Figure 3 is a local azimuthal temperature distribution caused by the geometry of the coolant holes. This superimposed temperature distribution has the form of $\Delta T = (10^{\circ}\text{F}) (\sin 216\theta)$, and is based on the assumption that the aluminum support ring remains flat and the nozzle-support ring interface is adiabatic.

The "O" ring between the aft support ring and the reflector could be eliminated by using a one piece barrel support ring, ^{if} Later detailed analyses indicates that this arrangement is unsatisfactory. No analysis was made of the leakage at this "O" ring because it would require a degree of detail well beyond conceptual phase analysis.

2.1.2 Flow Characteristics

2.1.2.1 Temperature Effects

As discussed above, temperatures in the aft support ring-nozzle flange area have been estimated (see Figure 3) to find thermal distortions in this region. The maximum temperature in the aft support ring is 400°R , which was found by assuming that hot gas from the core exit was directed over the surface of tungsten sheath. Another result of heating coming in from the core exit gas is that the average temperature of the fluid flowing through the holes leading to the aluminum reflector structure is increased, ^{by} $\text{---}^{\circ}\text{R}$.

2.1.2.2 Pressure Drop

The pressure drop for this design is considered reference and all designs will be compared to this design. During shut-down the pressure drop across the seal may be reversed, that is, during steady state the "U" seal may be primary but during shutdown the mating surfaces may become a good seal, leaving a pocket of high pressure which would tend to blow out the "U" seal.

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2.2 WEC CONCEPT 2 (DWG. NO. 982D250)

2.2.1 Radial Leakage Effects

The three "O" ring seals at the barrel, nozzle, vessel interface are the only available paths for leakage. Detailed thermal analysis of this region is necessary for structural analysis of distortions. This work is dependent on ANSC component details and should be done or supported by ANSC.

2.2.2.1 Temperature Effects

The extension of the aluminum barrel is cooled by the nozzle flange as well as the coolant flow through it. The flow split in the aluminum barrel extension causes an uncertainty in the amount of flow going to the aluminum barrel and the amount going to the beryllium part of the reflector. This would result in increased uncertainties in the temperature distribution in the reflector, especially near the aluminum barrel-beryllium segment interface.

2.2.2.2 Pressure Drop

The flow turnaround in the nozzle tubes introduces a pressure drop of approximately 7 psi. Flow turnaround in the nozzle flange introduces a pressure drop of approximately 50 psi due to the abrupt turns involved. The flow into the aluminum barrel will be at a different pressure than the flow into the beryllium part of the reflector and will affect the temperature uncertainties as mentioned above.

2.3 WEC CONCEPT 3 (DWG. NO. 982D252)

Unacceptable temperatures (greater than 1200°R) have been calculated in the aluminum wall at the nozzle chamber boundary. No further effort was expended on this concept.

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2.4 CONCEPT 4 (DWG. NO. 982D253)

2.4.1 Radial Leakage

Zero leakage can be assumed for the welded joints. Leakage in the two "O" rings requires detailed analysis of temperatures for the calculations of thermal distortions. This work is dependent on ANSC component details and should be done or supported by ANSC.

2.4.2 Flow Characteristics2.4.2.1 Temperature Effects

Temperatures in the aft support ring-nozzle flange area is the same as the reference design (Concept 1). Maximum temperature in the aluminum barrel is the same as Concept 1.

2.4.2.2 Pressure Drop

There is a pressure drop of approximately 50 psi in each flow turnaround in the nozzle, therefore, the total pressure drop will be 100 psi higher than the reference design (Concept 1). During steady state the flexible seal is forced against the nozzle and can be supported by the nozzle but during shutdown the backup "U" seal may keep a pressure of 450 psi between the flexible seal and the "U" seal while there is zero pressure in the reflector inlet plenum and the nozzle chamber. This may cause adverse loading effects on the seals in this design.

2.5 ANSC CONCEPT 1 (DWG. NO. 1137995)

2.5.1 Radial Leakage Effects

The seal is a "K" type seal. Data to permit a comparison of this seal with the "U" seal in the reference design is not available at this time.

2.5.2 Flow Characteristics2.5.2.1 Temperature Effects

Same as reference design (see 2.1.2.1).

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2.5.2.2 Pressure Drop

The pressure drop is approximately 25 psi higher than in the reference design.

2.6 ANSC CONCEPT 2 (DWG. NO. 1137995)

2.6.1 Radial Leakage Effects

A conical seal is used instead of the "K" seal in 2.5.1. Data to permit a comparison of this seal with the "U" seal in the reference design is not available at this time.

2.6.2 Flow Characteristics

See 2.5.2

2.7 ANSC CONCEPT 3 (DWG. NO. 1138044)

2.7.1 Leakage Effects

Zero leakage can be assumed at the welded joint. Leakage data for the "K" seal is not available at this time.

2.7.2 Flow Characteristics

2.7.2.1 Temperature Effects

Same as reference design (see 2.1.2.1)

2.7.2.2 Pressure Drop

The pressure drop is 30 psi higher than the reference design.

2.8 ANSC CONCEPT 4 (DWG. NO. 1138044)

2.8.1 Leakage Effects

Comparison of the "K" seal to the reference design cannot be made at this time.

2.8.2 Flow Characteristics

Same as 2.7.2

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Figure 1 Change in core exit temperature as a function of leakage
from the reflector inlet plenum to the nozzle chamber.

Figure 2 Leakage in the Nozzle--Aft Support Ring Seal as a Function of Pressure Drop Across The Seal

Figure 3 Azimuthal Temperature Distribution
in the Nozzle Flange at the Interface

FIGURE 4

Flow Rate in the Nozzle - Support Ring Joint as a Function of Gap Width

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SUBJECT (120) Nuclear Design Input In Support of the Reflector-Nozzle Design Trade Study						DRM TYPE (13) Analysis			
						DEPARTMENT (13) NRD			
						DATE (6) 5/22/70		REACTOR R-1	
PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM		
1.							1.	2.	
2.							3.	4.	
3.							5.	6.	
DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)									
1. Dwg. 982D251		2. Dwg. 982D250		3. Dwg. 982D252		4. Dwg. 982D253		5. Dwg. 1137995	
6. Dwg. 1137995		7. Dwg. 1138044		8. Dwg. 1138044		9. RD: 2527		10.	
1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)									
<u>PURPOSE</u> To provide in outline form the nuclear design information in support of the reflector-nozzle design study per change order W-70-6.									
<u>ASSUMPTIONS/METHODS AND CONCLUSIONS</u> 1.0 Introduction 1.1 Candidate Designs This DRM considers the nuclear characteristics of the candidate reflector-nozzle designs as defined in RD:2727 and listed below with their respective drawing numbers. 1.1.1 WEC Concept 1 - Conventional Reference Design (Dwg. 982D251) 1.1.2 WEC Concept 2 - Counterflow Nozzle Barrel Design (Dwg. 982D250) 1.1.3 WEC Concept 3 - Uni-Directional Flow Design (Dwg. 982D252) 1.1.4 WEC Concept 4 - Welded Corrugated Cylinder Design (Dwg. 982D253) 1.1.5 ANSC Concept 1 - Marman Clamp - Omega Seal (Dwg. 1137995) 1.1.6 ANSC Concept 2 - Marman Clamp - Conical Seal (Dwg. 1137995) 1.1.7 ANSC Concept 3 - Bolted Joint - Expandable Seal (Dwg. 1138044) 1.1.8 ANSC Concept 4 - Bolted Joint - Omega Seal (Dwg. 1138044)									
APPROVALS <div style="display: flex; justify-content: space-between;"> <div> PREPARED BY </div> <div> 5/22/70 DATE </div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div> APPROVED BY </div> <div> DATE </div> </div>			INFORMATION CATEGORY <div style="text-align: center;"> <u>Unclassified</u> CLASSIFICATION </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div> AUTHORIZED CLASSIFIER </div> <div> 5/22/70 DATE </div> </div>			SECURITY CLASS <div style="text-align: center; font-size: 1.2em;">UNCLASSIFIED</div>			

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1.2 Component Requirements

This analysis is directed toward an evaluation of the eight candidate designs described above insofar as they satisfy the following design requirements.

1.2.1 Nuclear Criticality

"The nuclear characteristics of this design shall not compromise the peak fuel loading constraint of 630 mg/cc for graphite fuel."

1.2.2 Reactor Control

"The total reactivity change available with control drum movement (Drum Span) shall be \$4.50."

2.0 Methods of Analysis

2.1 Reactivity Effects

The material mass differences relative to the candidate 1 reference design are determined for each candidate design. The reactivity effects of these mass differences are conservatively estimated using material reactivity worth coefficients at the core exit centerline as derived from PERT-ID neutron transport perturbation calculations.

The material worth coefficients with their core average values used in this study are.

<u>Material</u>	<u>Core Average Worth (¢ /lb)</u>	<u>Core Exit Center- Line Worth (¢ /lb)</u>
Aluminum	+0.49	+0.13
SS A286	+0.051	+0.023
SS 347	+0.030	+0.014
INC 718	+0.10	+0.042

2.2 Effect on Drum Span

The control drum poison geometry is identical in each of the candidate designs. Drum worth can be affected by material mass changes in the proximity of the control poison. However, since the changes are restricted to a location of relatively low poison worth, the effect on drum span should be negligible for each candidate design.

3.0 Results of Analysis

3.1 Design Candidate 1: WEC Concept 1 - Conventional Reference Design

3.1.1 Requirement: Nuclear Criticality

The peak uranium loading of 548 for the reference fuel design (Candidate 4 of the fuel trade study) is

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consistent with this reflector-nozzle candidate design. This loading does not exceed the peak loading constraint of 630 mg/cc for graphite fuel as specified by this requirement.

3.1.2 Requirement: Reactor Control

The reference fuel/reflector design with this reflector-nozzle candidate design has a drum span of \$4.50 as specified by this requirement.

3.2 Design Candidate 2: WEC Concept 2 - Counterflow Nozzle Barrel Design

3.2.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc for graphite fuel is not compromised due to the mass changes associated with this reflector-nozzle design.

This design has the following mass changes and corresponding reactivity effects relative to the reference (Design Candidate 1) design:

- A. An additional 105 lbs. of aluminum due to the extension of the Al structure to seat on the pressure vessel. (+14 ρ)
- B. A loss of 9 lbs. of A-286 due to the removal of the 18 attachment bolts. (no reactivity effect)

The net total reactivity change from the reference design is +14 ρ which is equivalent to a .5% peak loading decrease for reactivity balance.

Table 1 summarizes the important mass changes and reactivity effects of each candidate design.

3.2.2 Requirement: Reactor Control

The \$4.50 drum span requirement is not compromised in this design due to the location of the design changes in a region of low poison worth.

3.3 Design Candidate 3: WEC Concept 3 - Uni-Directional Flow Design

3.3.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc for graphite fuel is not compromised due to the mass changes associated with this reflector nozzle design.

The design has the following mass changes and corresponding reactivity effects relative to the reference (Design Candidate 1) design:

- A. An additional 125 lbs. of aluminum due to the extension of the Al structure. (+17 ρ)
- B. A loss of 310 lbs. of SS-347 due to removal of the nozzle barrel. (-4 ρ)

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- C. A loss of 9 lbs. of A-286 due to the removal of the 18 attachment bolts.
(no reactivity effect)

The net total reactivity change from the reference design is +13¢ which is equivalent to a .5% peak loading decrease for reactivity balance.

3.3.2 Requirement: Reactor Control

The \$4.50 drum span requirement is not compromised in this design due to the location of the design changes in a region of low poison worth.

3.4 Design Candidate 4: WEC Concept 4 - Welded Corrugated Cylinder Design

3.4.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc for graphite fuel is not compromised due to the mass changes associated with this reflector nozzle design.

This design has the following mass changes and corresponding reactivity effects relative to the reference (Design Candidate 1) design:

- A. An additional 8 lbs. of aluminum in the corrugated cylinder. (+1¢)
B. An additional 70 lbs. of SS 347 due to an increased nozzle barrel thickness.
(+1¢)

The net total reactivity change from the reference design is negligible (2¢).

3.5 Design Candidate 5: ANSC Concept 1 - Marman Clamp - Omega Seal

3.5.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc for graphite fuel is not compromised due to the mass changes associated with this reflector nozzle design.

The only mass difference between this design and the reference (Candidate 1) design is in the addition of approximately 8 lbs. of INC 718 due to the additional clamps. This change has a negligible effect on reactivity and, hence, the loading requirements are unchanged.

3.5.2 Requirement: Reactor Control

The \$4.50 drum span requirement is not compromised in this design due to the magnitude and location of the design changes in a region of low poison worth.

3.6 Design Candidate 6: ANSC Concept 2 - Marman Clamp - Conical Seal

3.6.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc for graphite fuel is not compromised due to the

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mass changes associated with this reflector nozzle design.

This design is equivalent masswise to the previous (Candidate 5) design and likewise differs from the reference design (Candidate 1) only in the addition of approximately 8 lbs. of INC 718 due to the clamps. As discussed previously, this change has a negligible effect on reactivity and, hence, the loading requirements are unchanged.

3.6.2 Requirement: Reactor Control

The \$4.50 drum span requirement is not compromised in this design due to the magnitude and location of the design changes in a region of low poison worth.

3.7 Design Candidate 7: ANSC Concept 3 - Bolted Joint - Expandable Seal

3.7.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc is not compromised due to the mass changes associated with this reflector nozzle design.

There are no significant mass differences between this design and the reference (Candidate 1) design.

3.7.2 Requirement: Reactor Control

The \$4.50 drum span requirement is satisfied by this design.

3.8 Design Candidate 8: ANSC Concept 4 - Bolted Joint - Omega Seal

3.8.1 Requirement: Nuclear Criticality

The peak uranium loading constraint of 630 mg/cc is not compromised due to the mass changes associated with this reflector nozzle design.

There are no significant mass differences between this design and the reference (Candidate 1) design.

3.8.2 Requirement: Reactor Control

The \$4.50 drum span requirement is satisfied by this design.

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TABLE 1

MASS CHANGES AND REACTIVITY EFFECTS OF THE REFLECTOR-NOZZLE
CANDIDATE DESIGNS RELATIVE TO THE REFERENCE (CANDIDATE 1) DESIGN

<u>Design</u>	<u>Significant Mass Changes From Reference Design</u>	<u>Reactivity Effect</u>
Conventional Reference Design	---	---
Counterflow Nozzle Barrel Design	+105 lbs. AL due to extension of the AL Structure - 9 lbs. A-286 due to removal of the attachment bolts	+14 ϵ
Uni-Directional Flow Design	+125 lbs. AL due to extension of the AL structure -310 lbs. SS-347 due to removal of the nozzle barrel - 9 lbs. due to removal of the attachment bolts	+13 ϵ
Welded Corrugated Cylinder Design	+ 8 lbs. AL due to the corrugated cylinder + 70 lbs. SS-347 due to an increased nozzle barrel thickness	+ 2 ϵ
Marman Clamp - Omega Seal	+ 8 lbs. INC-718 due to the addition of clamps	0
Marman Clamp - Conical Seal	+ 8 lbs. INC-718 due to the addition of clamps	0
Bolted Joint - Expandable Seal	No significant change	0
Bolted Joint - Omega Seal	No significant change	0

SECURITY CLASS <div style="text-align: center; font-weight: bold;">UNCLASSIFIED</div>		DATA RELEASE MEMORANDUM Westinghouse Astronuclear Laboratory CODE IDENT NO. 14683 <div style="text-align: right;">SHEET <u>1</u> OF <u>10</u></div>				DRM NO <div style="text-align: center;">52375</div> REV (1) <div style="text-align: center;">52375</div>			
SUBJECT (120) <div style="text-align: center; font-weight: bold;">RADIATION AND SHIELDING INPUT TO THE REFLECTOR TO NOZZLE TRADE STUDY</div>						DRM TYPE (13) <div style="text-align: center; font-weight: bold;">ANALYSIS</div> DEPARTMENT (13) Nuclear and Radiation Design			
						DATE (6) <div style="text-align: center;">5/21/70</div>		REACTOR <div style="text-align: center;">R-1</div>	
PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM		
1.	59						1.	2.	
2.							3.	4.	
3.							5.	6.	
DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)									
1. DRM 52605		2. DRM 51481A		3. DRM 51930		4. WANL-PR(LL)-010		5. DRM 51484	
6.		7.		8.		9.		10.	
1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)									
1. <u>PURPOSE:</u> To document the radiation and shielding analysis in support of the Reflector/Nozzle Trade Study.									
2. <u>ASSUMPTIONS/METHODS:</u> The assumptions and methods of analysis employed to obtain the results are reported in Section 2.0 of the attached document.									
3. <u>CONCLUSIONS:</u> The results of the radiation analysis are described in Section 3.0 of the attached document while a summary and conclusions for these results are presented in Section 4.0.									
APPROVALS <div style="text-align: center;"> <div style="display: flex; justify-content: space-between;"> PREPARED BY DATE 5/22/70 </div> </div>				INFORMATION CATEGORY <div style="text-align: center;"> <u>Unclassified</u> CLASSIFICATION </div>				SECURITY CLASS <div style="text-align: center; font-weight: bold;">UNCLASSIFIED</div>	
APPROVED BY _____ DATE _____				AUTHORIZED CLASSIFIER _____ DATE _____					

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1.0 INTRODUCTION

1.1 DESCRIPTION OF DESIGNS ANALYZED

The purpose of this analysis is to determine the effect of different reflector to nozzle designs on the Nuclear Subsystem and, in particular, the radiation characteristics of the system. The reflector to nozzle designs analyzed are defined in reference 1. Four of these concepts were proposed by WANL (WEC concepts 1 through 4) and four concepts were proposed by ANSC (ANSC concepts 1 through 4). All comparisons were made relative to the reference design which is WEC Concept 1.

1.2 DESCRIPTION OF DATA TO BE PRESENTED

This report provides radiation heating rates and the radiation environment for the reflector/nozzle interface region located aft of the reflector. In addition, the effect of the reflector to nozzle designs on the following is presented: 1) the photon source strength in the reflector aft end region, 2) the photon dose rates 30 feet forward of the core center on the reactor centerline, and 3) the internal shield weight needed to maintain the current dose rate levels external to the NSS.

1.3 COMPONENT REQUIREMENTS RELATED TO RADIATION

The radiation heating rate data is provided as input to thermal design analysis in order that the component requirements related to thermal analysis can be evaluated. The radiation environment data is provided as input to thermal and stress analyses so that the material properties at the proper irradiated conditions are obtained. Finally, the effect of the different reflector to nozzle designs on the dose rates external to the NSS are presented so that the internal shield weight changes needed to maintain the current radiation levels can be evaluated.

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2.0 METHOD OF ANALYSIS

2.1 ANALYTICAL MODELS

Reference 1 describes the geometrical arrangement of the design concepts analyzed in this report. The data in reference one were employed to calculate the weights of the components in the reflector aft end region. Reference 2 describes the R-Z geometry analytical model which was employed, in part, to obtain the calculated results presented.

2.2 ANALYTICAL METHODS

The calculational results are based, in part, on the analysis of the previous R-1 Reference Design defined by WANL Drawing 939J685E. The results of this analysis were obtained with the Westinghouse Integrated Standard Design Method (WISDM). The flow chart for these computations is given in Reference 3.

The analysis of the reflector to nozzle designs given in this report was performed by assuming that the neutron and photon fluxes obtained in the reflector aft end region of the former R-1 Reference Design (939J685E) were applicable to the current designs. The results obtained in this manner were then adjusted to current design of the NSS. This assumption will provide gross data which will provide accurate results for comparing one design relative to another. Detailed results in this off axis reactor region can be obtained only by performing two-dimensional calculations³ comparable to those performed for the previous R-1 Reference Design which was beyond the scope of analysis of this study.

The photon sources for the various reflector to nozzle designs were obtained from the NAGS code (Reference 4) and adjusted to the NSS design employed in this study. The photon radiation levels external to the NSS due to the reflector aft end region were calculated to be the product of the level obtained for the reflector aft end region in the former reference design and the ratio of the photon source strength for the reflector to nozzle design of interest to the source strength in this region for the former reference design. The change in internal

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shield weight required to make the external radiation levels equivalent to the current levels was obtained from parametric external radiation level data as a function of internal shield thickness reported in Reference 5.

3.0 RESULTS OF ANALYSIS

3.1 EFFECT OF REFLECTOR TO NOZZLE DESIGNS ON PHOTON SOURCE STRENGTH

Table 1 presents the photon source strength (Mev/sec) in the reflector aft end region for each of the reflector to nozzle designs considered in this analysis. Also included in this table is the ratio of the source strength of each design to the source strength for the reference design defined by WEC Concept 1. This table indicated that WEC Concept 4 has the highest source strength while WEC Concept 3 has the lowest source strength.

It should be noted that the source strength for WEC Concept 1 is a factor of 1.6 higher than the source strength in the reflector aft end region in the former R-1 Reference Design (939J685E) which was 6.20×10^{17} Mev/sec. The reason for this change is twofold. First, the WEC Concept 1 design differs from the former design in this area. Second, the region considered for this analysis extends further aft than the former reflector aft end region and therefore, includes more material which increases the photon source strength.

3.2 EFFECT OF REFLECTOR TO NOZZLE DESIGN ON INTERNAL SHIELD WEIGHT

In the former R-1 Reference Design defined by WANL Drawing 939J685E, the photon sources in the reflector aft end region contributed only 0.008 percent to the dose rate on the reactor centerline 30 feet forward of the core center. Table 1 indicated that WEC Concept 4 had the highest photon source strength of 1.2×10^{18} Mev/sec which is a factor of 2.0 higher than the source strength of the former Reference Design reflector aft end region. Therefore, while WEC Concept 4 represents a significant increase in the photon source strength, the change in the photon dose rate on the reactor centerline is less than 0.016 percent because the reflector aft end region represents such a small portion of the total dose rate at this location. Therefore, the change

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in the internal shield weight due the various reflector to nozzle designs is less than 5 pounds which represents an insignificant change in the internal shield weight.

3.3 REFLECTOR AFT END REGION HEATING RATES

Because the neutron and photon fluxes were assumed to be the same as those obtained for the former R-1 Reference Design, the average heating rate in the reflector aft end region remained unchanged on a heating rate per unit mass basis and the heating rate distribution was extrapolated to the current region boundaries. Figure 1 provides the relative axial distribution of volumetric heating rates in the reflector aft end and region at a power level of 1515 Mw. Fig. 2 provides the relative radial distribution of heating rates in this region. The heating rate at any location and for any material within this region is determined in the following manner:

1. Determine the value of the relative radial distribution of heating for the material and position of interest,
2. Determine the value of the relative axial distribution of heating for the material and location of interest,
3. Determine the average value of the heating rate from the curve (the average value of the heating rate appears on both the radial and axial distribution curves for this region), and
4. The heating rate for the material at the location of interest is the product of the average heating rate, the value of the relative radial distribution, and the value of the axial distribution.

3.4 REFLECTOR AFT END REGION RADIATION ENVIRONMENT

Because the neutron and photon fluxes were assumed to be the same as those obtained for the former R-1 Reference Design, the radiation environment is essentially the same for all reflector to nozzle designs. Table 2 supplies the reflector aft end region radiation environment at operating conditions (1515 Mw) to evaluate thermal and stress properties which are a function of

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radiation damage. This table supplies the thermal neutron flux ($E < 0.4$ ev), the fast neutron flux ($E > 1.0$ Mev), and the gamma ray dose rate (Rads-C/hr) for all reflector to nozzle designs. The radiation environment is provided at the aft face of the reflector at the inner and outer radius of the reflector.

Neutron fluences and gamma doses are obtained for the longest single burn and the total integrated power by multiplying this data by the factors supplied on Table 2. The factor for the longest single burn is based on the requirement for a one hour run during ground testing which will be longer than any single mission burn during flight. The factor for the total integrated power is based on ten hours of full power operation with minimal power being generated in the startup and shutdown ramps. At the present time, all of the requirements on the reactor operating profile have not been completely defined; therefore, as new information on the operating profile becomes available, the factors to be applied to the fluxes and dose rates to obtain fluences and doses will be modified to reflect the new information.

4.0 SUMMARY AND CONCLUSIONS

Table 1 displays the effect of reflector to nozzle designs on the photon source strength in the reflector aft end region. Table 2 displays the radiation environment at operating conditions (1515 Mw). Figures 1 and 2 display, respectively, the relative axial and relative radial distribution of radiation heating in the support plate.

The results of this analysis indicate that the reflector to nozzle designs have, relative to one another, a large difference in the photon source and show a significant increase in the photon source strength relative to the reflector aft end region in the former R-1 Reference Design (939J685E). This increase relative to the former R-1 design occurs primarily because the region represented in this analysis is larger in the axial dimension and, therefore, includes more material. Even though the source strength increases, the net effect of this change on the internal shield weight is negligible.

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TABLE 1

REFLECTOR TO NOZZLE REGION PHOTON SOURCE STRENGTHS

CONCEPT	DESCRIPTION	PHOTON SOURCE STRENGTH (Mev/Sec)	RATIO OF PHOTON SOURCE TO REFERENCE DESIGN
WEC CONCEPT 1	REFERENCE DESIGN	1.02 (18)	1.00
WEC CONCEPT 2	COUNTERFLOW NOZZLE BARREL	1.07 (18)	1.05
WEC CONCEPT 3	UNI - DIRECTIONAL FLOW	2.33 (17)	0.23
WEC CONCEPT 4	WELDED CORRUGATED CYLINDER	1.21 (18)	1.19
ANSC CONCEPT 1	MARMAN CLAMP - OMEGA SEAL	1.02 (18)	1.00
ANSC CONCEPT 2	MARMAN CLAMP - CONICAL SEAL	1.02 (18)	1.00
ANSC CONCEPT 3	BOLTED JOINT - EXPANDABLE SEAL	1.02 (18)	1.00
ANSC CONCEPT 4	BOLTED JOINT - OMEGA SEAL	1.02 (18)	1.00

NOTE: NUMBERS IN PARENTHESES REFER TO POWERS OF TEN.

TABLE 2

RADIATION ENVIRONMENT AT OPERATING CONDITIONS (1515 Mw) IN THE REFLECTOR
AFT END REGION FOR ALL REFLECTOR TO NOZZLE DESIGNS

LOCATION	NEUTRON FLUX (N/CM ² -SEC) ^(1, 2)		GAMMA RAY DOSE RATE ^(1, 3) (Rads-C/Hr)
	THERMAL (E<0.4 ev)	FAST (E>1.0 Mev)	
1. AFT FACE OF REFLECTOR (Reactor Station 52 In.) (R = 21.166 In.)	1.38 (14)	1.25 (14)	1.36 (9)
2. AFT FACE OF REFLECTOR (Reactor Station 52 In.) (R = 27.270 In.)	2.49 (13)	1.04 (14)	3.30 (8)

- (1) Numbers in Parentheses Refer to Powers of Ten.
- (2) The Neutron Fluences for the Longest Single Burn at 1515 Mw are Obtained by Multiplying the Data by 3.6 (3) While the Fluences for the Total Integrated Power are Obtained by Multiplying by 3.6 (4).
- (3) The Dose for the Longest Single Burn at 1515 Mw is Obtained by Multiplying the Data by 1.0 While the Dose for the Total Integrated Power is Obtained by Multiplying by 10.0.

Figure 1. Relative Axial Distribution of Heating in the Reflector
Aft End Region for all Reflector to Nozzle Designs

Figure 2. Relative Radial Distribution of Heating in the Reflector
Aft End Region for all Reflector to Nozzle Designs

ASTRONUCLEAR LABORATORY

TO: H. D. Kulikowski

cc: E. L. Layland
J. W. French
D. C. Thompson
E. M. Duran

From : Materials Department
WIN :
Date : 6 May 1970
Subject : Reflector-Nozzle Design
Trade Study

I have the following comments on the eight concepts of this study, listed in RD:2538.

1. WEC Concept 1
Satisfactory, assuming cooling satisfactory.
2. WEC Concept 2
Satisfactory.
3. WEC Concept 3
Welding of 6061 is not recommended for this sort of application,
nor is it felt that brazing would be feasible.
4. WEC Concept 4
Same as Concept 3.
5. ANSC Concept 1
No comment.
6. ANSC Concept 2
No comment.
7. ANSC Concept 3
If the seal ring and joint are properly designed, satisfactory welds
could probably be made for this design, assuming that the seal ring
is a weldable aluminum alloy.
8. ANSC Concept 4
No comment.

J. B. McAndrew

pfg

ME-480

From : Manufacturing Engineering
WIN :
Date : May 14, 1970
Subject: Fabrication Feasibility
Reflector-Nozzle Design
Trade Study
Ref. RD 2538

ASTRONUCLEAR LABORATORY

To: H. D. Kulikowski

cc: E. M. Duran

The following comments are offered for your use in subject trade study evaluation. They are based on the assumed manufacturing requirements to produce the components as indicated on the listed Study Layouts - 982D250-251-252-253 - WEC concepts 1-2-3-4, Dwg. 1137995 ANSC-concepts 1 and 2, and Dwg. 1138044-ANSC concepts 3 and 4.

REQUIREMENT

COMMENTS

982D251 - WEC #1

Threaded helicoil inserts for tie bolts (in cyl.)

Not feasible in a hole of this depth. Almost impossible to repair if damaged.

Flow holes in cyl.

Dia. to depth ratio difficult and expensive.

O.D. Machining on cyl.

Ribs with bosses for tie bolts difficult and expensive to machine out.

982D250 - WEC #2

Flow holes in cyl.

Dia. to depth ratio difficult and expensive.

982D252 - WEC #3

Flow holes in cyl. (blind)

Would require development to drill blind holes and intersect with blind holes.

Weld closure on flow channels.

Welding would be difficult to accomplish and inspect. Would also compound the machining requirements to meet final dimensions.

REQUIREMENT

COMMENTS

982D253 - WEC #3

Threaded helicoil inserts for tie bolts
(in cyl.)

Not feasible in a hole of this
depth. Almost impossible to
repair if damaged.

Flow holes in cyl.

Dia. to depth ratio difficult
and expensive.

Weld closure on corrugated member

Welding would be difficult to
accomplish and inspect. Would
also compound the machining
requirements to meet final dimensions.

Dwg. 1137995 - ANSC #1

Flow holes in cyl (blind)

Would require development to drill
blind holes and intersect with blind
holes.

Dwg. 1137995 - ANSC #2

Flow holes in cyl. (blind)

Would require development to drill
blind holes and intersect with
blind holes.

Dwg. 1138044 - ANSC #3

Flow holes in cyl. (blind)

Would require development to drill
blind holes and intersect with blind
holes.

Weld on expandable seal

Welding would be difficult to
accomplish and inspect. Would also
compound the machining requirements to
meet final dimensions.

Dwg. 1138044 - ANSC #4

Flow holes in cyl. (blind)

Would require development to drill
blind holes and intersect with blind
holes.

Conclusions

The aluminum cylinder forging is expected to not be entirely stress free since its configuration precludes stress relief by compression or tension. For this reason, it is expected that all close tolerance machining requirements will present some manufacturing problems.

The eight concepts can therefore be rated for their expected manufacturability in the following order.

982D251 - WEC - 2 - No. 1 best

982D250 WEC - 1 - No. 2

1137995-ANSC-2 - No. 3

1137995-ANSC-1 - No. 4

1138044-ANSC-4 - No. 5

1138044-ANSC-3 - No. 6

982D253 - WEC - 4 - No. 7

982D252 - WEC - 3 - No. 8

) ALL THREE CONSIDERED NOT FEASIBLE

C. B. Morgan

C. B. Morgan
Manufacturing Engineer

/cr

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		DRM TYPE (13) Analysis	
		DEPARTMENT (13) Reliability	

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SUBJECT (120) RELIABILITY EVALUATION - REFLECTOR-NOZZLE TRANSITION SEAL CONCEPTS		DATE (6)	REACTOR R-1
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PARA NO	CEI	PARA NO	CEI	PARA NO	CEI	TEST SCOPE NO	DATA ITEM
1. 3.1.2.1	55						1. 2.
2. 3.1.2.1	59						3. 4.
3.							5. 6.

DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)				
1. W-70-6	2. TD 70-27	3. 982D250	4. 982D251	5. 982D252
6. 982D253	7. 1137995	8. 1138044	9. EC 677559	10. DRM 52054

1. PURPOSE 2. ASSUMPTIONS/METHODS 3. CONCLUSIONS (USE CONTINUATION SHEET IF NECESSARY)

PURPOSE

The purpose of this DRM is to document the reliability analyses conducted on the Reflector-Nozzle Transition Seal Concepts.

ASSUMPTIONS/METHODS

A failure mode analysis (FMA) was conducted for each design concept where failure modes were postulated for each design configuration and relative failure probability estimates assigned. A system Failure Mode, Effects and Criticality Analysis (FMECA) was prepared to determine the severity ranking of all failure modes on the basis of the effect of failure determined from the FMECA. An overall failure estimate and a relative severity rating was calculated for each design concept. A "figure of merit" for each concept was derived using both overall failure estimates and criticality ranking as emphasis factors.

CONCLUSIONS

Selection of Reflector-Nozzle Transition Seal Concepts, based on the reliability figure of merit, indicates a reliability ranking order of:

APPROVALS <i>[Signature]</i> 5-22-70 PREPARED BY _____ DATE _____ APPROVED BY _____ DATE _____	INFORMATION CATEGORY UNCLASSIFIED CLASSIFICATION _____ AUTHORIZED CLASSIFIER _____ DATE _____	SECURITY CLASS
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1. Bolted Joint-Omega Seal, 1138044 - No. 4
or
V-Band Clamp-Omega Seal, 1137995 - No. 1
or
V-Band Clamp-Conical Seal, 1137995 - No. 2
2. Welded Corrugated Cylinder, 982D253
3. Counterflow Nozzle, 982D250
or
Bolted Joint-Expandable Seal, 1138044 - No. 3
4. Conventional Reference Design, 982D251
5. Uni-Directional Flow, 982D252

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RELIABILITY SUPPORTING DATA
REFLECTOR - NOZZLE TRANSITION, SEAL CONCEPTS
TRADE STUDY

INTRODUCTION

The reliability evaluation for the Reflector - Nozzle Transition, Seal Concepts Trade Study consists of the following:

1. A system failure mode, effects and criticality analysis (FMECA)
2. A component failure mode analysis (FMA) of each concept under consideration
3. Reliability modeling of the failure modes
4. Calculated relative reliability of each concept, using estimated relative failure probabilities

The system failure mode, effects and criticality analysis (FMECA) included as Table I is used to analyze the reflector - nozzle transition to assure a systematic review of the possible effects resulting from the transition failing to perform its design function. The basic functions considered in this study are those contained in the ECC specification for the NSS Reflector Assembly as related to the transition area under consideration. The effects on the reflector assembly itself and other nuclear subsystem components affected by the identified failure modes are listed. The effects on the nuclear subsystem are also evaluated. The criticality rating is then assigned based on the following definitions:

<u>Category</u>	<u>Definition</u>
I	Negligible effect. Failure produces no significant operational degradation or transient condition on the system.
II	Minor effect. Failure from which recovery can occur to complete the mission by switching or reverting to a recovery mode of operation.
III	Major effect. Failure or degradation which require mission abort and switching to an emergency mode of operation.
IV	Catastrophic effect. Failure results in direct crew injury, space craft damage, earth's population endangered and for which emergency action is required.

The failure mode analyses (FMA's), included as Tables 2 through 8, is the basis for analyzing each design concept to assure a systematic and detailed review of the possible ways that a component can fail to perform its design function. The estimate of the probability of failure for each way in which a failure mode can occur provides the basis for reliability assessment of each concept under consideration.

The FMA's for this trade study identifies the inability to meet intended functional requirements as the component mode of failure. The component mechanism of failure identifies those parts and the general manner in which they fail as the cause for the failure mode. For each identified mechanism of failure an estimated relative failure probability is assigned based on the following rating:

- 10^{-3} - High probability of failure
- 10^{-4} - Medium probability of failure
- 10^{-5} - Low probability of failure
- 10^{-6} - Very low probability of failure
- $<10^{-6}$ - Improbable likelihood of failure

Each mechanism of failure identified on the FMA's is reviewed for its effect on the nuclear subsystem, and a criticality category is assigned to each based on the effects of failure identified by the FMECA. Certain mechanisms of failure do not by themselves cause the identified failure mode. They must occur in conjunction with at least one other failure mechanism, i.e., a double failure must occur. For this study, only single failures will be considered in determining the criticality of the effects of failure. Hence, those failure mechanisms which must occur in conjunction with other failure mechanisms to produce a failure mode are given a criticality rating of I (negligible effect).

Having completed the FMECA and FMA's, it is possible to construct a reliability model from which the mechanism failure probabilities can be brought together into an overall concept reliability. For this trade study a relative probability is derived, since the area of concern is only a small portion of the total reflector assembly.

The reliability models for all the concepts under consideration are included in Figures 1 through 7. These are reliability block diagrams for the modes/mechanisms of failure considered significant to each design. Significant modes/mechanisms for the models are chosen as those having a criticality category, as related to the FMECA, of II, III or IV. Also included on Figures 1 through 7 are the mathematical equations for each reliability block diagram. The estimated relative probability of failure for each mode/mechanism is factored into the proper equation and the overall relative failure probability is calculated for each concept.

In addition to the overall failure probability for each concept under consideration, a relative severity of effect ranking is used as an aid in assessing the severity of effects of failure for each concept. This is done by weighting failure probability estimates, by the factors of 60% for Criticality IV, 30% for Criticality III, and 10% for Criticality II. The detailed explanation of the method used to develop the reliability figures of merit for the comparison matrix is obtained in a Trade Study Evaluation Procedure (WANL input to NRP-304).

For this trade study, the overall relative severity ranking introduced no difference in the order of ranking as that determined by the overall relative failure ranking. In addition, the individual severity figures of merit are not significantly different than the individual failure estimate figures of merit. Therefore, the results of the relative severity of effect ranking is not included in the Reliability Figure of Merit.

DISCUSSION

I. Reference Design, WANL 982D251

The overall relative failure estimate for this design concept is 60×10^{-6} .

In this concept there are two interfaces which require a seal; (1) reflector barrel/aft support ring joint, (2) aft support ring/nozzle barrel joint. The first (1) joint is held together by fastening the two members to each other. The second (2) joint is held together by pressure loads and/or the loads due to fastening each of the two members to another common member.

The failure postulated for this concept are leakage of the seals themselves and unloading of the aft support ring/nozzle barrel interface joint.

It is estimated that the most probable failure mechanisms are leakage of the seals, with the U-seal between the aft support ring/nozzle barrel being more likely to fail than the reflector barrel/aft support ring seal.

It is determined that all the identified failure modes/mechanisms for this concept result in leakage of propellant from the reflector inlet into the thrust chamber. All the mechanisms of failure then have the same effect on the NSS; hence, they have the same criticality rating. Since the effect of failure for this concept is major (Category III), all failure modes/mechanisms are by definition single point failures.

Improvement in this concept can be made by eliminating the reflector barrel/aft support ring interface joint, which would remove one seal. This appears feasible since some of the other concepts being considered in this trade study have been proposed on the basis of removing that seal. The resulting improvement in overall relative failure estimate would be small; however, going from 60×10^{-6} to 50×10^{-6} .

2. Counterflow Design, WANL 982D250

The overall relative failure estimate for this design concept is 21×10^{-6} .

In this concept there are two interfaces which require a seal; (1) reflector barrel/pressure vessel joint, (2) pressure vessel/nozzle flange joint. Both joints are held together by fastening the two members involved to each other. This approach eliminates the tie down attachment bolts in the reference design and fastens the reflector barrel directly to the pressure vessel. The nozzle barrel supports no compressive load and its primary function is to provide a flow path for coolant to cool the inner face of the extended reflector barrel.

The failures postulated for this concept are leakage of the seals themselves, unloading of the reflector barrel/pressure vessel interface joint, and failure of the counterflow tubing added to the nozzle.

It is estimated that the most probable failure mechanisms are leakage of the seals.

It is determined that all the identified failure modes/mechanisms for this concept result in leakage of propellant from either the nozzle tubing or the reflector inlet into the thrust chamber. This assumes that failure of one bolt in the reflector barrel/pressure vessel joint will locally unload the joint sufficiently to cause significant leakage. This approach is conservative, but by estimating a failure probability for one bolt to be improbable (less than 10^{-6}) it becomes insignificant in the calculation of the overall concept failure probability. All the mechanisms of failure then have the same effect on the NSS, and they have the same criticality rating. Since the effect of failure for this concept is major (Criticality III, all failure modes/mechanisms are by definition single point failures.

For this concept there is no readily apparent way of improving the reliability.

3. Uni-Directional Flow, WANL 982D252

The overall relative failure estimate for this design concept is 220×10^{-6} .

In this concept the interface joints and load path are the same as in Concept 2, Counterflow Design, WANL 982D250. The unique difference in this concept is that, the nozzle barrel has been eliminated, and the nozzle flow is directed through individual passageways at the inner face of the pressure vessel flange and at the inner face of the reflector barrel extension. For the reliability considerations of this trade study it is assumed this concept provides sufficient cooling of the pressure vessel flange and reflector barrel extension.

The failures postulated for this concept are leakage of the seals themselves, unloading of the reflector barrel/pressure vessel interface joint, and failure of the individual passages in the pressure vessel flange and reflector barrel extension resulting in overheating of the failed part due to leakage causing reduction of coolant flow.

It is estimated that the most probable failure mechanism is failure of the individual passages in either the pressure vessel or the reflector barrel extension.

It is determined that all the identified failure modes/mechanisms for this concept result in propellant leakage causing overheating of the pressure vessel and/or reflector barrel and loss of structural rigidity of these items. Since they carry the axial load of the NSS the reflector would become displaced and move in the aft direction, resulting in rupture of support stem and feed bypass lines and possible structural damage to other NSS components. All the mechanisms of failure then have the same effect on the NSS, and they have the same criticality rating. Since the effect of failure for this concept is catastrophic (Criticality IV) all failure modes/mechanisms are by definition single point failures.

For this concept improvement in reliability may be accomplished if the reflector barrel extension and pressure vessel could be protected from thrust chamber temperature.

4. Welded Corrugated Cylinder, WANL 982D253

The overall relative failure estimate for this design concept is 15×10^{-6} .

In this concept the load path is the same as in Concept 1, Reference Design, WANL 982D251. All interface joints are the same as in Concept 1, Reference Design, except for an added seal at the pressure vessel/nozzle flange interface joint. The unique difference in this concept is the addition of a large corrugated cylinder which is seal welded to the aft support ring at one end and the pressure vessel at the other end. This cylinder is between the reflector inlet chamber and the nozzle barrel and requires the nozzle barrel to have a counterflow path similar to Concept 2, Counterflow Design, WANL 982D250. The major difference with this counterflow nozzle barrel is that the load path is through the nozzle barrel as in Concept 1, Reference Design, WANL 982D251. The corrugated cylinder is a primary seal along with the added seal at the pressure vessel/nozzle flange interface. These are backed up by the U-seal at the aft support ring/nozzle barrel joint.

The failures postulated for this concept are leakage of the primary seals, leakage of the secondary seal, failure of the counterflow tubing added to the nozzle, and unloading of the aft support ring/nozzle barrel interface joint.

It is estimated that the most probable failure mechanisms are leakage of seals, one of which is a primary seal between the aft support ring/reflector barrel joint.

This concept provides some redundancy in sealing the reflector inlet plenum from the thrust chamber that is not present in previous design concepts. Some of the identified failure mode/mechanisms are redundant and require a double failure to result in a significant effect (leakage) to the NSS. Those mechanisms of failure which are redundant are considered to have a negligible (Criticality I) effect on the NSS by themselves. In combination with other mechanisms of failure the effect on the NSS becomes major (Criticality III); therefore, they are included in the reliability model for this concept, Figure 4. Certain other identified failure mode/mechanisms result directly in leakage of propellant from either the nozzle tubing or the reflector inlet plenum into the thrust chamber. This effect of failure is major (Criticality III), hence, these mechanisms of failure are by definition single point failures.

Improvement in this concept can be made by eliminating the reflector barrel/aft support ring interface joint, which would remove one seal. This appears feasible since some of the other concepts being considered in this trade study have been proposed on the basis of removing that seal. The resulting improvement in overall relative failure estimate would be from

5. V-Band Clamp-Omega Seal, ANSC 1137995 Concept 1

The overall relative failure estimate for this design concept is 10×10^{-6} .

In this concept the load path is the same as in Concept 1, Reference Design, WANL 982D251. In addition, a V-Band clamp is utilized at the reflector barrel/nozzle barrel interface joint to provide a redundant method for clamping the joint. The U-seal is also replaced by an omega type metal seal, and the aft support ring/reflector barrel interface joint has been eliminated.

The failures postulated for this concept are leakage of the seal, failure of the redundant methods for clamping the reflector barrel/nozzle barrel interface joint, and unloading the interface joint and redundant V-Band Clamp.

It is estimated that the most probable failure mechanisms are leakage of the seal, and failure of the V-Band clamp.

This concept provides redundancy in the method for clamping the interface joint; therefore; a double failure is required to result in unloading the interface joint and causing leakage. Those mechanisms of failure which are redundant are considered to have a negligible (Criticality I) effect on the NSS by themselves. In combination with other mechanisms of failure the effect on the NSS becomes major (Criticality III); therefore, they are included in the reliability model for this concept, Figure 5. Leakage of the seal and unloading the interface joint results in propellant flow from the reflector inlet plenum into the thrust chamber. This effect of failure is major (Criticality III), hence, these mechanisms of failure are by definition single point failures.

For this concept improvement in reliability may be accomplished by providing a double seal at the interface joint. The resulting improvement in overall relative failure estimate would be from 10×10^{-6} to something less than 10^{-6} .

6. V-Band Clamp-Conical Seal, ANSC 1137995 Concept 2

The overall relative failure estimate for this design concept is 10×10^{-6} .

This concept is identical to Concept 5, V-Band Clamp-Omega Seal, ANSC 1137995 Concept 1, except a conical seal is used in place of the omega seal.

All comments regarding Concept 5 are applicable to this concept also.

7. Bolted Joint-Expandable Seal, ANSC 1138044, Concept 3

The overall relative failure estimate for this design concept is 20×10^{-6} .

In this concept the load path is the same as in Concept 1, Reference Design, WANL 982D251. At the interface joint a ring is added between the reflector barrel and nozzle barrel, necessitating another seal. The ring is fastened to the nozzle barrel with bolts, thus compressing the added seal. The U-seal is welded to the ring and to the reflector barrel at its outer edges.

The failure postulated for this concept are leakage of the seal, failure of the seal welds, unloading of the ring/nozzle barrel joint, and unloading of the reflector barrel/nozzle barrel interface joint.

It is estimated that the most probable failure mechanisms are leakage of the fixed seal, and failure of the welded joint on the expandable seal.

It is determined that most of the identified failure modes/mechanisms for this concept result in leakage of propellant from the reflector inlet plenum into the thrust chamber. These mechanisms of failure have the same effect on the NSS and the same criticality rating. Since the effect of failure is major (Criticality III) these failure modes/mechanisms are by definition single point failures. This concept provides a form of redundancy in clamping the reflector barrel/nozzle barrel interface joint in that failure of two sets of fasteners are required to result in leakage of the propellant from the reflector inlet plenum into the thrust chamber. Those mechanisms of failure which are redundant are considered to have a negligible (Criticality I) effect on the NSS by

themselves. In combination with other mechanisms of failure the effect on the NSS becomes major (Criticality III); therefore, they are included in the reliability model for this concept, Figure 6.

Improvement in this concept can be made by eliminating the ring and added seal. This is what the next concept has done.

8. Bolted Joint-Omega Seal, ANSC 1138044, Concept 4

The overall relative failure estimate for this design concept is 10×10^{-6} .

In this concept the load path is the same as in Concept 1, Reference Design, WANL 982D251. At the interface joint the U-seal is replaced by an omega type seal and the joint is additionally clamped with bolts through the nozzle barrel into the reflector barrel.

The failures postulated for this concept are leakage of the seal itself and unloading of the interface joint.

It is estimated that the most probable failure mechanism is leakage of the seal.

In this concept leakage of the seal results directly in leakage of propellant from the reflector inlet plenum into the thrust chamber. The effect of this failure on the NSS is major (Criticality III) and by definition this mechanism of failure is a single point failure. There is redundancy in the method of clamping the joint in this concept. The identified failure mode/mechanisms associated with unloading the joint require failure of two sets of fasteners to result in a significant effect (leakage) to the NSS. Those mechanisms of failure which are redundant are considered to have a negligible (Criticality I) effect on the NSS by themselves. In combination with other mechanisms of failure the effect on the NSS becomes major (Criticality III); therefore, they are included in the reliability model for this concept, Figure 7.

Improvement in reliability may be accomplished by providing a double seal at the interface joint. The resulting improvement in overall relative failure estimate would be from 10×10^{-6} to something less than 10^{-6} .

CONCLUSION

The ranking of the concepts based on the overall relative reliability estimate is found to be as follows:

<u>Concept</u>	<u>OFE</u>
Bolted Joint-Omega Seal	10×10^{-6}
V-Band Clamp-Omega Seal	10×10^{-6}
V-Band Clamp-Conical Seal	10×10^{-6}
Welded Corrugated Cylinder	15×10^{-6}
Bolted Joint-Expandable Seal	20×10^{-6}
Counterflow Nozzle	21×10^{-6}
Reference Design	60×10^{-6}
Uni-Directional Flow	220×10^{-6}

As noted in the discussion each concept as proposed contains single point failures. It should be noted, however, that in most cases the estimated probability of the single point failure occurring is low. Though the ultimate objective is to eliminate single point failures completely, it may not be possible or practical, in which case the design must be such to reduce the probability of failure to very low levels. A review of the NSS and Engine shows that numerous failure modes, if they occur, are single point failures. Some examples of this are; Rupturing of propellant line, failure of the reflector assembly structure, structural failure of the core support plate, loss of flow to the support stems. In each of these cases, careful attention must be directed toward high reliability.

FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS

See Mode

PREPARED BY I. R. Spezialetti

COMPONENT Reflector Assembly

DWG NO. Ident. Column

APPROVED BY

DATE May 11, 1970

PAGE 1 OF 1

W59048

Mode Ident. No.	FAILURE MODE	Crit. Cat.	COMPONENT EFFECT	SUBSYSTEM EFFECT	ENGINE EFFECT	MEANS OF DETECTION
For Concepts 982D250 982D251 982D253 1137995, Nos. 1 & 2 1138044, Nos. 3 & 4	Reflector fails to prevent radial leakage of the propellant flow	III	Reflector inlet flow is not all channeled through to the reflector outlet plenum, but rather some flow is leaked through the reflector-nozzle transition joint and shunted directly into the thrust chamber. Since less than the pumped amount of propellant is delivered to the core, the fuel temperature will rise for the rated heat generation output of the core.	Nuclear subsystem will show a temperature profile at the core exit with colder temperature at the periphery due to the shunted leakage flow. Also the core may degrade due to reactivity loss resulting from likelihood of corrosion at higher operating temperature.		Pressure sensors for reflector to core exit ΔP . Temperature sensors in the core and/or thrust chamber.
For Concept 982D252	Reflector fails to transmit axial forces	IV	Reflector loses its structural rigidity and becomes displaced within the limitations of surrounding components. However, the displacement of the reflector causes movement in the aft direction of the core, core support plate and shield, and results in rupturing of support stem feed and bypass lines, and possible jamming of control drums.	Nuclear subsystem cannot continue operating at rated steady state conditions without further severe damage to the subsystem.		Temperature and pressure sensors at various locations within the subsystem.

TABLE 1

COMPONENT FAILURE MODES ANALYSIS

SHEET 1 OF 1DATE May 4, 1970 PREPARED BY I. R. SpezialettiDEPARTMENT NERVA ReliabilitySUBSYSTEM Reflector Assembly

DATE _____ APPROVED BY _____

COMPONENT Reflector - Nozzle Transition DWG NUMBERS 982D251
Reference Design

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Reflector Barrel/Aft Support Ring interface joint leaks	1. Metal seal leaks	III	10^{-5}
2.0	Aft Support Ring/Nozzle Barrel Interface joint leaks	1. Metal seal leaks	III	5×10^{-5}
		2. Aft Support Ring distorts	III	$<10^{-6}$
3.0	Reflector Barrel/Pressure Vessel joint fastening fails	1. Tie Down(s) fail	III	$<10^{-6}$
		2. Tie Down(s) jack-up and unload seal joint	III	$<10^{-6}$

COMPONENT FAILURE MODES ANALYSISSHEET 1 OF 1DATE May 4, 1970 PREPARED BY I. R. Spezialetti DEPARTMENT NERVA Reliability SUBSYSTEM Reflector AssemblyDATE _____ APPROVED BY _____ COMPONENT Reflector - Nozzle Transition DWG NUMBERS 982D250
Counter Flow

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Reflector Barrel/Pressure Vessel interface joint leaks	1. Metal seal leaks	III	10^{-5}
2.0	Pressure Vessel/Nozzle Flange interface joint leaks internally	1. Metal seal leaks	III	10^{-5}
3.0	Reflector Barrel/Pressure Vessel joint fastening fails	1. Bolt(s) fail	III	$<10^{-6}$
4.0	Added Nozzle Counter-Flow Tubing leaks	1. Tubing fails or tubing joints fail	III	10^{-6}

COMPONENT FAILURE MODES ANALYSIS

SHEET 1 OF 1DATE May 4, 1970 PREPARED BY I. R. SpezialettiDEPARTMENT NERVA ReliabilitySUBSYSTEM Reflector Assembly

DATE _____ APPROVED BY _____

COMPONENT Reflector - Nozzle Transition DWG NUMBERS 982D252
Uni-Directional Flow

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Reflector Barrel/Pressure Vessel interface joint leaks	I. Metal seal leaks	IV	10^{-5}
2.0	Pressure Vessel/Nozzle Flange interface joint leaks internally	I. Metal seal leaks	IV	10^{-5}
3.0	Reflector Barrel weld joints for individual passages leak	I. Structural failure of weld joints or tubes	IV	10^{-4}
4.0	Pressure Vessel weld joints for individual passages leak	I. Structural failure of weld joints or tubes	IV	10^{-4}
5.0	Reflector Barrel/Pressure Vessel joint fastening fails	I. Bolt(s) fail	IV	$<10^{-6}$

5
COMPONENT FAILURE MODES ANALYSIS

SHEET 1 OF 1

DATE May 4, 1970 PREPARED BY I. R. Spezialetti DEPARTMENT NERVA Reliability SUBSYSTEM Reflector Assembly
DATE _____ APPROVED BY _____ COMPONENT Reflector - Nozzle Transition DWG NUMBERS 982D253
Welded Corrugated Cylinder

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Pressure Vessel/Nozzle Flange interface joint leaks	1. Metal seal leaks	III	10^{-5}
2.0	Aft Support Ring/Nozzle Barrel interface joint leaks, and corrugated cylinder leaks	1. Metal seal leaks 2. Aft Support Ring distorts 3. Structural failure of weld joints or cylinder	I I I	5×10^{-5} $<10^{-6}$ 10^{-6}
3.0	Reflector Barrel/Aft Support Ring interface joint leaks	1. Metal seal leaks	III	10^{-5}
4.0	Reflector Barrel/Pressure Vessel joint fastening fails	1. Tie Down(s) fail 2. Tie Down(s) jack-up and unload seal joint	I I	$<10^{-6}$ $<10^{-6}$
5.0	Added Nozzle Counter Flow Tubing leaks	1. Tubing fails or tubing joints fail 2. Reflector/Nozzle interface end fails	I III	10^{-6} 5×10^{-6}

COMPONENT FAILURE MODES ANALYSIS

SHEET 1 OF 1

DATE May 6, 1970 PREPARED BY I. R. Spezialetti DEPARTMENT NERVA Reliability SUBSYSTEM _____
 DATE _____ APPROVED BY _____ COMPONENT _____ DWG NUMBERS 1137995 Concept 1
and Concept 2

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Aft Support Ring/Nozzle Barrel Interface joint leaks	1. Metal seal fails	III	10^{-5}
		2. V-Band Clamp fails	I	10^{-5}
		3. Tie Down(s) fail	I	$<10^{-6}$
		4. Tie Down(s) jack-up and unload seal joint	III	$<10^{-6}$

COMPONENT FAILURE MODES ANALYSIS

SHEET 1 OF 1DATE May 6, 1970 PREPARED BY I. R. Spezialetti DEPARTMENT NERVA Reliability SUBSYSTEM _____DATE _____ APPROVED BY _____ COMPONENT _____ DWG NUMBERS 1138044Concept 3

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Reflector Barrel/Nozzle Barrel Interface joint leaks	1. Fixed seal leaks 2. Expandable seal weld cracks 3. Bolt(s) fail, distorting seal ring	III III III	10^{-5} 10^{-5} $<10^{-6}$
2.0	Reflector Barrel/Pressure Vessel joint fastening fails	1. Tie Down(s) fail 2. Tie Down(s) jack-up and unload seal joint	I I	$<10^{-6}$ $<10^{-6}$

COMPONENT FAILURE MODES ANALYSIS

SHEET 1 OF 1

DATE May 6, 1970 PREPARED BY I. R. Spezialetti DEPARTMENT NERVA Reliability SUBSYSTEM _____

DATE _____ APPROVED BY _____ COMPONENT _____ DWG NUMBERS 1138044

Concept 4

W59150

Mode Ident. No.	Component Failure Mode of Failure	Component Mechanism of Failure	Criticality Category	Failure Probability Rating
1.0	Reflector Barrel/Nozzle Barrel Interface joint leaks	1. Metal seal leaks	III	10^{-5}
2.0	Reflector Barrel/Pressure Vessel Joint fastening fails and Reflector Barrel/Nozzle Barrel Bolt(s) fail	1. Tie Down(s) fail 2. Bolt(s) fail 3. Tie Down(s) jack-up and unload seal joint	I I I	$<10^{-6}$ $<10^{-6}$ $<10^{-6}$

FIGURE 1
RELIABILITY MODEL AND MATH EQUATION
(WANL 982D251, REFERENCE DESIGN CONCEPT)

$$R = R_1 \times R_2 \times R_3 \times R_4 \times R_5$$

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$


```
graph LR; A[Reflector Barrel/Pressure Vessel Seal Leaks] --> B[Pressure Vessel/Nozzle Flange Seal Leaks]; B --> C[Added Nozzle Counter-flow Tubing Leaks]; C --> D["X" Number Bolts at Reflector/Pressure Vessel Joint Fail];
```

1 Reflector Barrel/Pressure Vessel Seal Leaks

2 Pressure Vessel/Nozzle Flange Seal Leaks

3 Added Nozzle Counter-flow Tubing Leaks

4 "X" Number Bolts at Reflector/Pressure Vessel Joint Fail

$$Q = Q_1 + Q_2 + Q_3 + Q_4$$

FIGURE 3
RELIABILITY MODEL AND MATH EQUATION
(WANL 982D25T, UNI-DIRECTIONAL FLOW CONCEPT)

$$R = R_1 \times R_2 \times R_3 \times R_4 \times R_5$$

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$

FIGURE 4

RELIABILITY MODEL AND MATH EQUATION
(WANL 982D253, WELDED CORRUGATED CYLINDER CONCEPT)

$$R = \left[\left(R_1 \times R_2 \times R_3 \right) + \left(R_4 \times R_5 \times R_6 \times R_7 \right) - \left(R_1 \times R_2 \times R_3 \times R_4 \times R_5 \times R_6 \times R_7 \right) \right] \times R_8 \times R_9$$

$$Q = \left[\left(Q_1 + Q_2 + Q_3 \right) \times \left(Q_4 + Q_5 + Q_6 + Q_7 \right) \right] + Q_8 + Q_9$$

FIGURE 5
RELIABILITY MODEL AND MATH EQUATION
 (ANSC 1137995, CONCEPT 1 AND 2)

$$R = R_1 \times (R_2 + R_3 - R_2 \times R_3) \times R_4$$

$$Q = Q_1 + (Q_2 \times Q_3) + Q_4$$

FIGURE 6

RELIABILITY MODEL AND MATH EQUATION

(ANSC 1138044, CONCEPT 3)

$$R = R_1 \times R_2 \times R_3 \times (R_4 + R_5 - R_4 \times R_5)$$

$$Q = Q_1 + Q_2 + Q_3 + (Q_4 \times Q_5)$$

FIGURE 7

RELIABILITY MODEL AND MATH EQUATION

(ANSC 1138044, CONCEPT 4)

$$R = R_1 \times (R_2 + R_3 - R_2 \times R_3) \times (R_4 + R_5 - R_4 \times R_5)$$

$$Q = Q_1 + (Q_2 \times Q_3) + (Q_4 \times Q_5)$$

NOMENCLATURE		ASTRONUCLEAR LABORATORY COMPARISON MATRIX OF DESIGN APPROACHES								SELECTION
RELIABILITY CONSIDERATIONS		1 WANL 982D251 Reference Design	2 WANL 982D250 Counterflow	3 WANL 982D252 Uni-Directional Flow	4 WANL 982D253 Welded Corrugated Cyl.	5 ANSC 1137995 Seal Concept No. 1	6 ANSC 1137995 Seal Concept No. 2	7 ANSC 1138044 Seal Concept No. 3	8 ANSC 1138044 Seal Concept No. 4	
FUNCTIONAL & TECHNICAL DESIGN REQUIREMENTS										
Overall Failure Estimate		(.103) 21 x 10 ⁻⁶	(.034) 60 x 10 ⁻⁶	(.009) 220 x 10 ⁻⁶	(.136) 15 x 10 ⁻⁶	(.205) 10 x 10 ⁻⁶	(.205) 10 x 10 ⁻⁶	(.103) 20 x 10 ⁻⁶	(.205) 10 x 10 ⁻⁶	
Most Probable Failure Modes		Aft Support Ring/ Nozzle Skirt Seal Leaks	Reflector Barrel/Pres- sure Vessel Seal Leaks Pressure Vessel Nozzle Seal Leaks	Reflector Barrel weld for Individual Flow Passages Leak Pressure Vessel for Individual Flow Passages Leak	Reflector/Aft Support Ring Seal Leaks	Reflector Barrel/ Nozzle Skirt Seal Leaks	Reflector Barrel/	Expansion Seal weld joint fails Nozzle Skirt/Nozzle Ring Seal Leaks	Reflector Barrel/Nozzle Skirt Seal Leaks	
Reliability Figure of Merit		0.103	0.034	0.007	0.1365	0.2055	0.2055	0.103	0.2055	(5, 6, 8), 4, (1, 7), 3, 2

MAY 12 REC'D

SS-136-70

ASTRONUCLEAR LABORATORY

TO: Mr. H. D. Kulikowski

cc: Mr. E. H. Hemmerle

From : Systems Safety
WIN :
Date : May 11, 1970
Subject : Systems Safety Input to Reflector -
Nozzle Design Trade Study

The following material is presented in response to your request for Systems Safety input to the Reflector/Nozzle Design Trade Study.

Four items were chosen for safety evaluation of the various Reflector/Nozzle transition concepts.

- 1) Sensitivity to thermal transients resulting from such malfunctions as the failure of 1 SSCV and transition to single SSCV operation.
- 2) Capability to perform in the E.O.M. following drum(s) out malfunctions which would produce local hot-spots in the periphery flow.
- 3) Capability to survive pressure transients:
 - a) Moderately large overpressures in the reflector inlet chamber could result from TPA over-runs.
 - b) Reverse transient pressure differentials leading to structural damage could result from such malfunctions as TPA failures.
- 4) Emergency cooldown requirements could be substantially increased by some of the proposed concepts.

The following two matrices contain SS's evaluation of the WEC and ANSC concepts.

M. R. Trammell

M. R. Trammell
Systems Safety

/lad

Attachments (2)

SAFETY EVALUATION ANSC CONCEPTS

<u>Safety Criteria</u>	<u>ANSC Concept 1</u>	<u>ANSC Concept 2</u>	<u>ANSC Concept 3</u>	<u>ANSC Concept 4</u>	<u>Relative Rating</u>
1. Thermal Transients	No (little) exposed Al	Same as ANSC Concept 1	Differential expansion of nozzle and Al flange could damage seal	Same as ANSC Concept 1	(1, 2, 4), 3
2. E.O.M. Operation	No particular sensitivity	Same as 1	Same as 1	Same as 1	(1, 2, 3, 4)
3. Pressure Transients					
a. Overpressure	No particular sensitivity	Same as 1	Same as 1	Same as 1	(1, 2, 3, 4)
b. Reverse Pressure	Leakage could tend to unseat Marman clamp	Same as 1	Possible permanent damage to seal welds	Possible temporary leakage. No permanent damage	4, (1, 2), 3
4. Cooldown Requirements	Same as WANL reference	Same as 1	Same as 1	Same as 1	(1, 2, 3, 4) 4, (1, 2), 3

SAFETY EVALUATION OF WEC CONCEPTS

<u>Safety Criteria</u>	<u>WEC Concept 1 (Reference)</u>	<u>WEC Concept 2 (Counterflow Nozzle Barrel)</u>	<u>WEC Concept 3 (Uni-Directioned Flow)</u>	<u>WEC Concept 4 (Corrugated Cylinder)</u>	<u>Relative Rating</u>
1. Thermal Transients	Al support ring in exposed area (Adequate)	Al structure well protected. No load on nozzle barrel (Good)	Al structure and tubes in exposed and sensitive position (Poor)	Same as WEC Concept 1 (Adequate)	2, (1, 4), 3
2. E.O.M. Operation	Al support ring in exposed area (Adequate)	Al structure well protected (Good)	Al structure and tubes in exposed and sensitive position (Poor)	Same as WEC Concept 1 (Adequate)	2, (1, 4), 3
3. Pressure Transients					
a. Overpressure	Combined thermal and pressure effects could cause Al support ring failure	Al structure well protected. No thermal effect accompanying overpressure	High possibility of catastrophic failure under combined thermal and hydraulic conditions. Aluminum tubes subject to failure under overpressures	Same as WEC Concept 1. In addition, Overpressure could cause corrugated cylinder to damage counterflow nozzle section	2, 1, 4, 3
b. Reverse Pressure Transient	Reverse pressure could cause temporary seal leakage without permanent damage (Adequate)	No obvious detrimental result (Good)	No obvious detrimental result except possible Al tube distortion (Poor)	Possible damage to corrugated cylinder and cylinder - support ring weld (Marginal)	2, 1, 4, 3
4. Cooldown Requirements	This is reference case (Adequate)	Requirements no greater than reference (Adequate)	Substantially increased requirement likely (Poor)	Requirements no greater than reference (Adequate)	(1, 2, 4), 3

2, 1, 4, 3