REPORT NO. RN-TM-0584

MASTER

NUCLEAR ROCKET OPERATION²

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REPORT NO. RN-TM-0584

SHIELDING TRADE STUDY
INTERIM STATUS REPORT
TASKS 2 AND 2A AND RELATED STUDIES

NUCLEAR ROCKET OPERATIONS

MAY 1969

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RN-TM-0584

SHIELDING TRADE STUDY

INTERIM STATUS REPORT

(Tasks 2 & 2A and Related Studies)

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I. Introduction

This report is intended as an interim document to make available a written record of much of the work performed in the Shielding Trade Study¹ during the period from December 20, 1968, to April 20, 1969. The work was performed under Tasks 2 and 2A of the Shielding Trade Study^{2,3}. In addition, the results of Task 1 of the Trade Study, i.e., the development of a reviewed Common Radiation Analysis Model, are reported in RN-TM-583.

It is anticipated that further studies will significantly reduce total shield weights. This study is only intended to compare the trade off between disk and brim shields on a consistent basis. The system shield weight requirements for each mission in the Program Requirements Document (PRD)⁴ and a Direct Lunar Landing Mission are reported herein for several approaches to the shield design problem.

Comparisons are made between Variable Internal and Brim Shielding and Disk Shielding with Capsule Shielding. Variations involving capsule shielding in addition to engine shielding are also discussed. Two propellant tank configurations were studied, a 60° extended conical tank bottom and a 75° tank bottom configuration.

Some of the systems implications of the engine shield configurations and their qualification testing are very briefly discussed.

II. Summary

As a result of the study of the manned shielding requirements conducted during the past 18 months, the primary candidate shield configurations are:

Engine Disk Shielding

Engine Brim and Variable Internal Shielding

Capsule (Payload) Shielding

Either of the engine shield configurations could be used in conjunction with capsule shielding. However, sufficient data are not available to allow a reasonable statement of weight requirements if all or most of the shield weight is at the capsule. That is to say, the engine shields have been studied in detail with methods which are not much different than the more sophisticated Monte Carlo analytical technique - as long as the shield is at the source. Only straight exponential curves are available for the capsule shields and the less sophisticated techniques do not apply when one is trying to shield the detector (i.e., the crew) locally.

Table 1 summarizes the system shield weights for four categories of missions using the engine disk shield configuration. In this approach a single internal shield is designed to meet the unmanned mission requirements and an uncooled disk shield is added to the engine to accomplish the various manned missions. For missions such as the Substitute Synchronous Orbit Ferry Mission the engine disk shield is augmented by several thousand pounds of capsule shielding (included in the weights of Table 1).

Table 2 summarizes the system shield weights for the same missions using the approach of a variable internal shield with a cooled brim shield which extends beyond the radius of the pressure vessel to shield the line and nozzle sources and radiation leakage from the side of the PVARA.

TABLE 1

SHIELD WEIGHT PER MISSION WITH 75° CONICAL BOTTOM LH₂ TANK
AND ENGINE DISK SHIELD

<u>Mission</u>	<u>Payload Avail.</u>	<u>Shield Weight (lbs)</u>			<u>Total</u>
		<u>Internal</u>	<u>Disk</u>	<u>Capsule</u>	
Grand Tour (Unmanned)	-	3,300	-	-	3,300
Sub. Syn. Orbit Ferry (4 burns)*	3	3,300	11,400	8,000	22,700
Sub. Syn. Orbit Ferry (3 burns)*	3	3,300	11,400	4,500	19,200
One-way Syn. Orbit	30	3,300	1,400	-	4,700
	> 50	3,300	-	-	3,300
ω Direct Lunar Landing	30	3,300	2,400	-	5,700
	> 50	3,300	-	-	3,300

*i.e., separation of the manned payload after the third or fourth burn

NOTE: Shield weight can be redistributed from engine to a 60" radius capsule disk with the same total weights quoted above; however, large weight redistributions cannot be made without sophisticated Monte Carlo analyses of the capsule shield effectiveness.

TABLE 2

SHIELD WEIGHT PER MISSION WITH 75° CONICAL BOTTOM LH₂ TANK
AND VARIABLE INTERNAL AND BRIM SHIELDS

<u>Mission</u>	<u>Payload Attn.</u>	<u>Shield Weight (lbs)</u>			
		<u>Variable Internal</u>	<u>Brim</u>	<u>Capsule</u>	<u>Total</u>
Grand Tour (Unmanned)	-	3,300	-	-	3,300
Sub. Syn. Orbit Ferry (4 burns)*	3	6,300	7,800	8,000	22,100
Sub. Syn. Orbit Ferry (3 burns)*	3	6,300	7,800	4,500	18,600
One-way Syn. Orbit	30	4,700	-	-	4,700
	> 50	3,300	-	-	3,300
Direct Lunar Landing	30	5,000	-	500	5,500
	> 50	3,300	-	-	3,300

*i.e., separation of the manned payload after the third or fourth burn

NOTE: Shield weight can be redistributed from engine to a 60" radius capsule disk with the same total weights quoted above; however, large weight redistributions cannot be made without sophisticated Monte Carlo analyses of the capsule shield effectiveness.

The data in Tables 1 and 2 are for a 75° extended conical tank bottom configuration. Similar system weights are presented in Tables 3 and 4 for the 60° extended conical tank bottom configuration. In Table 3, however, another variable is introduced, namely increased engine/tank bottom separation distance. An adequate shadow shield is provided by the variable internal and brim shield and therefore separation distance is not a variable in Table 4. In order to effect the desired shadow cone, separation distances from core center to the tank bottom must be greater than 200" when disk shields are used in conjunction with the 60° conical tank. Separation distance is not a variable for either the brim or disk shield configurations when used in conjunction with a 75° conical tank.

Figure 1 shows how the variable internal and brim shield weight compares with the disk shield weight for a 75° conical tank configuration. Figure 2 shows how they compare for a 60° conical tank configuration.

Although the 75° tank weighs more than the 60° tank the weight increase is more than made up for by the shield weight decrease as can be seen in Figures 3 and 4, for the disk and brim shields respectively.

Figure 5 shows the "effective shadow cone" provided by either a brim or disk shield approach. The radiation levels at the tank top are controlled by controlling radiation leakage at the source (i.e., the engine). Figure 6 shows pictorially how a capsule shield "effective shadow" is projected into the capsule of the Substitute Synchronous Orbit Ferry Mission. In this case, tank top doses in excess of 1,000 Rem must be attenuated by shielding the detector (i.e., the crew compartment) to the desired level (i.e., 10 Rem). Figure 7 shows pictorially how a combination of engine and capsule shielding would work.

TABLE 3

SHIELD WEIGHT PER MISSION WITH 60° CONICAL BOTTOM LH₂ TANK
AND ENGINE DISK SHIELD

<u>Mission</u>	<u>Payload Attn.</u>	<u>Shield Weight (lbs)</u>			<u>Shield Weight Total</u>	<u>Separation Distance Weight Penalty</u>	<u>Total System Weight</u>
		<u>Internal</u>	<u>Disk</u>	<u>Capsule</u>			
Grand Tour (Unmanned)	-	3,300	-	-	3,300	-	3,300
Sub. Syn. Orbit Ferry	3	3,300	14,700	3,000	21,000	3,300	24,300
		3,300	9,600	3,000	15,900	3,300	19,200
One-way Syn. Orbit	30	3,300	3,300	-	6,600	1,000	7,600
o	> 50	3,300	-	-	3,300	-	3,300
Direct Lunar Landing	30	3,300	2,000	-	5,300	3,300	8,600
	> 50	3,300	-	-	3,300	-	3,300

TABLE 4

SHIELD WEIGHT PER MISSION WITH 60° CONICAL BOTTOM LH₂ TANK
AND VARIABLE INTERNAL AND BRIM SHIELDS

<u>Mission</u>	<u>Payload Attn.</u>	<u>Shield Weight (lbs)</u>			
		<u>Variable Internal</u>	<u>Brim</u>	<u>Capsule</u>	<u>Total</u>
Grand Tour (Unmanned)	-	3,300	-	-	3,300
Sub. Syn. Orbit Ferry (4 burns)*	3	9,300	12,000	3,000	24,300
Sub. Syn. Orbit Ferry (3 burns)*	3	7,300	10,700	3,000	21,000
One-way Syn. Orbit	30	5,000	2,500	-	7,500
	> 50	3,300	-	-	3,300
Direct Lunar Landing	30	5,000	3,500	-	8,500
	> 50	3,300	-	-	3,300

*i.e., separation of the manned payload after the third or fourth burn

NOTE: Shield weight can be redistributed from engine to a 60" radius capsule disk with the same total weights quoted above; however, large weight redistributions cannot be made without sophisticated Monte Carlo analyses of the capsule shield effectiveness.

FIGURE 1
 ENVELOPE CURVES - BRIM AND DISK SHIELDS
 75° TANK WITH 200" S.D., PAYLOAD
 ATTENUATION FACTOR = 1.0
 (7500 LB. RESIDUAL LH₂ AT END OF FIRING)

FIGURE 3
 DISK SHIELD ENVELOPE CURVES WITH 60° TANK AND 75° TANK FOR 200" S.D.,
 FERRY MISSION CONFIGURATION, PAYLOAD ATTENUATION FACTOR = 1.0,
 3300 LB. INTERNAL SHIELD
 (7500 LB. RESIDUAL LB₂ AT END OF FIRING)

FIGURE 4

BRIM SHIELD ENVELOPE CURVES WITH 60° TANK
AND 75° TANK FOR 200° S.D., FERRY MISSION CONFIGURATION,
PAYLOAD ATTENUATION FACTOR = 1.0, 3300 LB. INTERNAL SHIELD
(7500 LB. RESIDUAL LB₂ AT END OF FIRING)

FIGURE 5

EFFECTIVE SHADOW CONE FOR DISK OR BRIM SHIELDS

FIGURE 6

EFFECTIVE SHADOW CONE FOR CAPSULE SHIELD

SUB. SYN. ORBIT FERRY MISSION
CONFIGURATION WITH VARIOUS SHIELD CONFIGURATIONS

FIGURE 7
EFFECTIVE SHADOW CONES FOR A COMBINATION
OF SHIELDS

The development of "envelope" curves, which represent minimum shield weights for either the brim or disk shield approach, is described and the data are presented to show how the envelope curves are arrived at. Capsule shielding curves are single exponential curves from point kernel scattering codes. No attempt was made to develop "envelope" curves for the capsule shielding. Only preliminary capsule shield evaluations are included to scope the potential of that method of solving the shield problem either with or without engine shielding. The distributed nature of the sensitive detectors (i.e., six astronauts) results in a requirement to shield the entire crew compartment, as shown in Figure 7.

It should be pointed out that engine shielding provides an environment for the payload which gives the same amount of protection for a one man crew or a six man crew by essentially providing a cone of protection for the payload. It remains to be demonstrated whether capsule shielding weight would be reduced substantially if the crew complement were reduced. This is so due to the preponderance of scattered radiation entering the payload.

From Tables 1 through 4, it can be clearly seen that the indigenous payload attenuation is an important variable in manned mission shielding. Current estimates indicate that the Direct Lunar Landing Mission Payload which weighs 161,750 lbs is approximately equivalent to 17,000 lbs of radiation shielding. That is to say, that this payload is 10% as effective as a slab shield but that the weight is dual purpose, and after all is the payload which the mission is designed to transport. Payload redesign might increase this useful percentage, but it is anticipated to be a major engineering effort.

III. Engine and Shield Layouts

The 75,000 lbs thrust NERVA engine layout configurations along with shield concepts to indicate the mechanical design background for this study are described in this section. Five engine layouts, forming the base for the nuclear analytical models, are presented.

Figure 8 is an unmanned configuration requiring no external shielding. All lines are "straight routed", the nozzle skirt is 70:1, and the distance from core center to the tank bottom is 186 inches.

Figure 9 depicts a manned flight engine with an external disk shield inserted in the middle portion of the lower thrust structure. All lines are "straight routed" except in the area of the shield, the nozzle skirt is 70:1, and the distance from core center to the tank bottom is 200 inches.

Figure 10 shows a manned flight engine with an external brim shield at the forward pressure vessel periphery. All lines are "straight routed" except to clear the brim shield, the brim shield is shown cooled with full pump discharge flow, the nozzle skirt is 70:1, and the distance from core center to the tank bottom is 200 inches.

Configurations 8, 9 and 10 formed the basis for the present studies. Figure 11 and 12 were reduced to mathematical models in Task 1 and will be analyzed in Task 3 of the Shielding Trade Study.

Figure 11 is a manned flight engine with an external disk shield. All lines are tucked-in as close as possible to the pressure vessel, the nozzle skirt is 100:1, and the distance from core center to the tank bottom is 200 inches.

Figure 12 shows a manned flight engine with an external brim shield. All lines are tucked-in, the brim shield is shown cooled with full pump dis-

FIGURE 8

75K NERVA FLIGHT ENGINE - 1135234
(UNMANNED CONCEPT)

FIGURE 9

75K NERVA FLIGHT ENGINE - 1135230
(DISK SHIELD CONCEPT, STRAIGHT ROUTED LINES)

○ EXTERNAL DISK SHIELD DIA	100"
○ MAXIMUM EXTERNAL DISK SHIELD THICKNESS	10"
○ DISTANCE FROM PROPELLANT TANK BOTTOM TO CORE CENTER	200"

FIGURE 10

75K NERVA FLIGHT ENGINE - 1135232
(BRIM SHIELD CONCEPT, STRAIGHT ROUTED LINES)

- EXTERNAL BRIM SHIELD DIA 100"
- DISTANCE FROM PROPELLANT TANK BOTTOM TO CORE CENTER 200"

FIGURE 11

75K NERVA FLIGHT ENGINE - 1135231
(DISK SHIELD CONCEPT, TUCKED-IN LINES)

FIGURE 12

75K NERVA FLIGHT ENGINE - 1135233
(BRIM SHIELD CONCEPT, TUCKED-IN LINES)

- EXTERNAL BRIM SHIELD DIA 100"
- DISTANCE FROM PROPELLANT TANK BOTTOM TO CORE CENTER 200"

charge flow, the nozzle skirt is 100:1, and the distance from core center to the tank bottom is 200 inches.

The following materials were used for the line and nozzle source calculations: aluminum - PDL, Hast-C - TIL, zircalloy-2 - TEL, Hast-X - Pressure Nozzle, CRES-347 - Nozzle Skirt and Skirt Extension. The turbine exhaust line material has been changed from zircalloy-2 to Hast-C in subsequent analyses, not reported in this document.

A mechanical design concept is presented in Figure 13 for a 50 inch radius disk shield consisting of layers of lithium hydride, stainless steel and graphite. The center portion is 10 inches thick with a 7 inch periphery. The lithium hydride is shown "canned" in stainless steel and stainless steel is also employed to support the graphite layer. Thrust structure attachment is accomplished by bolting through the lithium hydride and graphite to the structurally adequate stainless steel.

Two mechanical design concepts are presented in Figures 14 and 15 for a brim shield cooled by LH₂ from the pump discharge line. The designs depict 37 inch radius and 50 inch radius shields comprised of lithium hydride, lead, boral, and liquid hydrogen as the shielding materials. Both concepts show a torus-type structural shell, encompassing the shielding materials, which supports the nuclear shield material layers and contains the high pressure pump discharge hydrogen. The torus-shape selected is thought to offer the lightest weight design consistent with the shape of the shielding material.

Weights are calculated and presented in Tables 5 and 6 for the individual shield designs (50 inch radius disk, 37 inch radius brim, 50 inch radius brim) and as deltas to a basic unmanned engine weight.

FIGURE 13
DISK SHIELD - 1136182

FWD
↑

FIGURE 14
BRIM SHIELD CONCEPT - 1136132

25

TABLE 5
CONCEPTUAL SHIELD WEIGHT

○ BRIM

	<u>37 IN. R</u>	<u>50 IN. R</u>
PRESSURE SHELL	520	985
PRESSURE SHELL FASTENERS	90	90
SHIELD SUPPORT STRUCTURE	105	200
LITHIUM HYDRIDE CANS	50	125
SUB-TOTAL	<u>765</u>	<u>1400</u>
LITHIUM HYDRIDE	210	510
BORAL	140	500
LEAD	3665	4100
LH ₂	50	110
SUB-TOTAL	<u>4065</u>	<u>5220</u>

TOTAL *4830 LBS

*6620 LBS

○ DISK

	<u>50 IN. R</u>
GRAPHITE SUPPORT PLATES	600
LITHIUM HYDRIDE CANS	1245
FASTENERS	80
SUB-TOTAL	<u>1925</u>
LITHIUM HYDRIDE	405
GRAPHITE	1110
BORATED CRES.	7190
SUB-TOTAL	<u>8705</u>

* DOES NOT INCLUDE CENTRAL SHIELD

TOTAL.... 10,630 LBS

TABLE 6
 Δ TO BASIC (UNMANNED) ENGINE WEIGHT

	37" R		50" R		50" R	
	BRIM		BRIM		DISK	
	ON	OFF	ON	OFF	ON	OFF
PRESSURE VESSEL EXTENSION	70	70	70	70	-	-
PRESSURE VESSEL FLANGES	160	160	160	160	-	-
LINE ALTERATIONS	10	30	10	30	30	30
WIRING EXTENSION	5	5	5	5	30	30
THRUST STRUCTURE EXTENSION + FLANGES	-	-	-	-	50	50
THRUST STRUCTURE SPACER	-	-	-	-	-	150
EXTERNAL SHIELD	4830	-	6620	-	10630	-
ADDITIONAL CENTRAL SHIELDING	TBD	-	TBD	-	-	-

Δ TO BASIC ENGINE WT . .

5075 LBS + TBD CENTRAL SHIELD	260 LBS	6865 LBS + TBD CENTRAL SHIELD	260 LBS	10740 LBS	230 LBS
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IV. 75° Tank Configuration Weight Trade Study

The purpose of a study on the 75° LH₂ tank configuration was to ascertain the optimum amount of shielding to be located at the engine for a particular level of radiation at a point approximately 11 ft. forward of the LH₂ tank. This point is a candidate couch location for the Substitute Synchronous Orbit Ferry Mission. Two different modes of engine shielding were studied, viz additional internal and brim shielding and disk shielding.

The results of analyses made for the 75° tank are reported in this section. These results are based on point kernel computer codes. The calculations are based on drainage of the LH₂ to 7500 pound residual LH₂ in the tank. Dose rates are obtained as a function of LH₂ level, or time at a fixed flow rate, and an integration is performed over time to obtain the crew dose.

IV. A. Variable Internal and Brim Shielding

By adding additional internal shielding, the direct contribution, and to a lesser extent, the scattered contribution of the PVARA sources to the crew dose may be decreased. Likewise, the addition of a brim shield will decrease the lines and nozzle direct and scattered contributions as well as the PVARA scattered. There is an optimum combination of the two shields to produce the lowest crew dose for any additional shield weight. Since this additional shield might cause weight penalties in the form of non-useable structure (i.e., non-useable from a shielding standpoint), additional weight will be referred to as Δ system weight.

A parametric study was performed wherein the internal shield was varied from the base configuration of 3,300 lbs by adding 0, 2,000, 4,000 and 6,000 lbs additional internal shielding. This was done first with no brim shield and then with brim shields of 37.5", 42", 46" and 50" radius. Three brim shield thicknesses were considered. The resultant crew dose is plotted vs. Δ system weight for these shield weights in Figure 16. An envelope curve was then drawn through the minimum weight points in this parametric study. It is not possible to have data points below this envelope curve within the limits of the study. Other parameters such as shaping of the shield might perturb this envelope.

It should be noted that these data include a penalty for non-useable structural weights which is a variable with brim shield radius.

FIGURE 16

CREW DOSE VS Δ SYSTEM WEIGHT - INTERNAL & BRIM SHIELD - 200" S.C., 75° TANK

FERRY MISSION CONFIGURATION, PAYLOAD ATTENUATION FACTOR = 1.0,

3500 LB. INTERNAL SHIELD

(7500 LBS. RESIDUAL LB₂ AT END OF FIRING)

IV. B. Disk Shielding

The analysis for the disk shielding was handled in much the same manner as the previous section with 0, 2,000, 4,000 and 6,000 lbs central disk shields in combination with variable thickness peripheral disk shields of 9, 40", 45", 50" and 54" radius. The results are shown in Figure 17, a series of curves which define the envelope curve of crew dose vs. Δ system weight.

C. Single Capsule Shield

The envelope data from the variable internal and brim and disk shields are compared in Table 7 and depicted graphically in Figure 18. The slope of these curves is quite significant. The steeper the slope the better the shield. Three effects cause the change in slope in these curves: (a) initially the curves are steep because only the PVARA 25" radius is reflected in the weights (i.e., the first 2,000 lbs), (b) spectral hardening or filtering out of the lower energy radiation affects the medium range of these curves, (c) finally, scattering around the shadow shields dominates near the end of the curves and, in fact, they would become asymmetric if extended far enough.

A possible location for shielding is at the capsule. The LH_2 and GH_2 in the tank cause a spectral shift resulting in a buildup of lower energy radiation due to repeated scattering in the tank. Therefore, shielding at the capsule is essentially shielding a softer spectrum of photons. On the other hand, this multiple scattering also makes such shielding calculations difficult. Straight exponential curves are quite misleading due to this.

FIGURE 17

CREW DOSE VS Δ SYSTEM WEIGHT-UNCOOLED DISK SHIELD - 200" S.D., 75° TANK,
 FERRY MISSION CONFIGURATION, PAYLOAD ATTENUATION FACTOR = 1.0,
 3300 LB. INTERNAL SHIELD
 (7500 LBS RESIDUAL Li_2 AT END OF FIRING)

TABLE 7
CREW DOSE SUMMARY FROM ENVELOPE CURVES
75° TANK

<u>Δ System Weight (lbs)</u>	<u>200" SD Disk</u>	<u>200" SD Brim</u>
4800	1493	-
4960	-	1493
6000	960	960
7000	765	765
8000	625	620
9000	510	502
10000	420	407
11000	349	330
12000	286	266
13000	237	215
14000	197	175
15000	163	143
16000	136	118
17000	114	98
18000	97.5	84

FIGURE 18

ENVELOPE CURVES - BRIM AND DISK SHIELDS
 75° TANK WITH 200" S.D., PAYLOAD
 ATTENUATION FACTOR = 1.0
 (7500 LB. RESIDUAL LH₂ AT END OF FIRING)

The capsule shield used in this portion of the analysis was assumed to be a 10 foot diameter disk constructed of steel. Figure 19 depicts the idealized exponential attenuation of this shield as a function of shield weight for the PVARA and TIL sources with both the direct and scattered components. Figure 20 gives the same data for lead. Admittedly, lead is the better shield material, as can be seen from the curves. These curves were produced by a single scatter code with no provision for scattering in the capsule. This type of scatter problem is considered to be soluble only by Monte Carlo calculations. Since the calculations performed in this study are intended to be of a scoping nature only and since the steepness of both the lead and steel curves is due to ignoring the payload scatter, i.e., straight attenuation only, it was decided to use the steel curve for capsule shield calculations. This is an engineering judgement of the type of actual weights which would result by using a lead capsule shield with an appropriate scatter shield. To further simplify the study at this point, the TIL scatter curve was used for all sources.

FIGURE 19

FIGURE 20

Capsule shielding is discussed in more detail in a later section. The intent of the discussion in this section is to introduce the curves of Figure since they were employed in the generation of system weight tables for the February 14 SNPO review.⁴

D. System Weight for 10 Rem - SNPO Presentation February 13, 1969

In order to meet the required crew dose of 10 Rem⁵, shielding must be added over and above any geometric and material attenuation provided by the nuclear stage and payload. The payload attenuation factors used in this report are the indigenous shielding provided by the materials in the payload. The geometric falloff to the astronaut locations is taken account of in the basic calculations. Since the payload attenuation factor is a very difficult calculational result, the problem was approached herein in a parametric fashion where payload attenuation factors of 1, 3, 10, 30 and 100 were used. A payload attenuation factor of 1.0 means no attenuation in the payload.

Table 8 gives a weight breakdown for the two shield conditions and five payload attenuation factors. The payload attenuation factors can then be plotted vs. the Δ system weight for the variable internal and brim shield and for the disk shield cases, Figure 21. As can be seen, the two cases are very similar with a maximum difference of about 400 lbs. With no spacecraft attenuation the Δ system weight is 28,200 lbs to obtain a crew dose of 10 Rem for the two cases.

TABLE 8

Δ SYSTEM WEIGHT FOR 10 REM WITH 7500 LB RESIDUAL LH₂ IN 75° TANK - 200" S.D.

PAYLOAD ATTN. FACTOR Δ SYST. WEIGHT (LBS)	UNCOOLED DISK SHIELDS					VARIABLE INTERNAL & BRIM SHIELDS				
	100	30	10	3	1	100	30	10	3	1
External Disk Shield	2250	8150	10750	16400	21600					
Add. Int. & Brim Shields						2250	7900	10300	16350	21600
Shield at Payload	0	0	3000	3000	3000	0	0	3000	3000	3000
Separation Distance	300	300	300	300	300	300	300	300	300	300
Basic Int. Shield	3300	3300	3300	3300	3300	3300	3300	3300	3300	3300
TOTAL	5850	11750	17350	23000	28200	5850	11500	16900	22950	28200

FIGURE 21

SYSTEM WEIGHT INCREMENT FOR 10 REM WITH VARYING
PAYLOAD ATTENUATION FOR BRIM SHIELD AND UN-
COOLED DISK SHIELD - 75° TANK, 200" S.D.

IV. E. Contributions to Crew Dose by Individual Source

The breakdown of various contributors to the crew dose for a 75° tank case is given in Table 9. The data are normalized to unity such that a comparison can be made. As can be seen, approximately half the dose is from the PVARA sources, the remainder being lines and nozzle contributions. The secondary gamma from the brim shield is included in that case due to its importance. The disk shield is not a high source of secondary gamma radiation due to the shielding provided by the internal shield from the neutron flux of the reactor.

TABLE 9

CREW DOSE COMPOSITION WITH TYPICAL BRIM AND DISK
SHIELDS FOR FERRY MISSION CONFIGURATION WITH 75° TANK, 200" S.D.

<u>Source</u>	<u>Fraction of Crew Dose</u>	
	<u>Brim Shield</u>	<u>Disk Shield</u>
PVARA Direct	.208	.151
PVARA Scatter	.206	.362
LH ₂ Capture	<u>.005</u>	<u>.010</u>
Total PVARA	.419	.524
Nozzle & Skirt Direct	.001	.001
Nozzle & Skirt Scatter	.083	.146
Skirt Exten. Direct	.044	.050
Skirt Exten. Scatter	.082	.065
TEL Direct (Zirc 2)	.003	.003
TEL Scatter (Zirc 2)	.006	.006
TIL Direct	.045	.051
TIL Scatter	.048	.045
PDL Direct	.047	.053
PDL Scatter	<u>.060</u>	<u>.056</u>
Total Lines & Nozzle	.418	.476
External Shield Capture	<u>.163</u>	<u> </u>
TOTAL	1.000	1.000

V. 60° Tank Configuration Weight Trade Study

Presented in this section are the results from a study on the 60° long conic bottom LH₂ tank configuration shield weights. The methods used in these analyses are as used in the 75° tank study. Several different separation distances between core center and tank bottom were considered (viz 200", 250" and 356").

V. A. Variable Internal and Brim Shielding

By adding additional internal shielding, the direct contribution, and to a lesser extent, the scattered contribution of the PVARA sources to the crew dose may be decreased. Likewise, the addition of a brim shield will decrease the lines and nozzle direct and scattered contributions as well as the PVARA scattered. There is an optimum combination of the two shields to produce the lowest crew dose for any additional shield weight. Since this additional shield might cause weight penalties in the form of non-useable structure (i.e., non-useable from a shielding standpoint), additional weight will be referred to as Δ system weight.

A parametric study was performed wherein the internal shield was varied from the base configuration of 3,300 lbs by adding 0, 2,000, 4,000 and 6,000 lbs additional internal shielding. This was done first with no brim shield and then with brim shields from 33" to 54" radius. Three brim shield thicknesses were considered. The resultant crew dose is plotted vs. Δ system weight for these shield weights in Figures 22-24. An envelope curve was then drawn through the minimum weight points in this parametric study. It is not possible to have data points below this envelope curve within the limits of the study. Other parameters such as shaping of the shield might perturb this envelope.

It should be noted that these data include a penalty for non-useable structural weights which is a variable with brim shield radius.

FIGURE 22

CREW DOSE VS Δ SYSTEM WEIGHT - INTERNAL & BRIM SHIELD - 200" S.D., 60° TANK,

FERRY MISSION CONFIGURATION, PAYLOAD ATTENUATION FACTOR = 1.0,

3300 LB. INTERNAL SHIELD

(7500 LBS. RESIDUAL LE_2 AT END OF FIRING)

FIGURE 23

FIGURE 24

V. B. Disk Shielding

The analysis for the disk shielding was handled in much the same manner as the previous section with 0, 2,000, 4,000 and 6,000 lbs central disk shields in combination with variable thickness peripheral disk shields of 9, 40", 45", 50" and 54" radius. The results are shown in Figures 25-27, a series of curves which define the envelope curve of crew dose vs. _ system weight.

C. Single Capsule Shield

The envelope data from the two preceding sections are presented again, Table 10, and depicted graphically in Figure 28. A single exponential attenuation was applied in the February 14 SNPO review based on TIL scattered spectra and steel attenuating properties. The single straight exponential curve is only valid for up to two mean free paths (a factor of 7 attenuation).

D. System Weight for 10 Rem

As was done for the 75° tank configuration, capsule shield weights were calculated for the three separation distances and are presented in Tables 11-13. These tables give a breakdown of the various Δ system weights to arrive at several payload attenuation factors viz. 100, 30, 10, 3 and 1. This is based on a crew dose of 10 Rem when the payload attenuation factor is 1.

The total Δ system weight from these six tables can be plotted vs. the payload attenuation factor as depicted in Figure 29. Of greatest importance is the fact that the curves lie practically on top of one another. The message contained herein is that there is virtually no difference between additional internal and brim shielding and disk shielding. In fact, separation distance really buys no weight savings due to the weight penalties which must be paid for separating.

FIGURE 25

CREW DOSE VS Δ SYSTEM WEIGHT - UNCOOLED DISK SHIELD - 250" S.D., 60° TANK,
FERRY MISSION CONFIGURATION, PAYLOAD ATTENUATION FACTOR - 1.0,
3300 LB. INTERNAL SHIELD
(7500 LBS. RESIDUAL LH₂ AT END OF FIRING)

FIGURE 27

TABLE 10

CREW DOSE SUMMARY FROM ENVELOPE CURVES - 60° TANK

<u>Δ SYSTEM WT. (LBS)</u>	<u>200" S.D. DISK</u>	<u>250" S.D. DISK</u>	<u>356" S.D. DISK</u>	<u>200" S.D. INT. & BRIM</u>	<u>250" S.D. INT. & BRIM</u>	<u>356" S.D. INT. & BRIM</u>
3600	2379	----	----	----	----	----
3760	----	----	----	2379	----	----
4650	----	2016	----	----	----	----
4810	----	----	----	----	2016	----
6880	----	----	1455	----	----	----
7040	----	----	----	----	----	1455
4000	2080	----	----	----	----	----
5000	1615	----	----	1540	----	----
6000	1330	1290	----	1230	1290	----
7000	1130	1045	1360	1010	1045	----
8000	975	875	915	830	860	925
9000	850	755	695	685	710	702
10000	750	660	547	565	595	570
11000	660	585	441	467	500	447
12000	598	522	356	390	420	384
13000	540	470	290	326	352	315
14000	495	424	240	274	294	250
15000	460	383	199	230	246	196
16000	433	351	167	197	205	157

TABLE 10 (continued)

CREW DOSE SUMMARY FROM ENVELOPE CURVES - 60° TANK

<u>Δ SYSTEM WT. (LBS)</u>	<u>200" S.D. DISK</u>	<u>250" S.D. DISK</u>	<u>356" S.D. DISK</u>	<u>200" S.D. INT. & BRIM</u>	<u>250" S.D. INT. & BRIM</u>	<u>356" S.D. INT. & BRIM</u>
17000	417	328	140	167	173	126
18000	400	310	121	143	147	102

FIGURE 28

ENVELOPE CURVES - BRIM AND DISK SHIELDS,
60° TANK, PAYLOAD ATTENUATION = 1.0

TABLE 11

Δ SYSTEM WEIGHT FOR 10 REM WITH 7,500 LB RESIDUAL LH₂ IN 60° TANK - 200" S.D.

PAYLOAD ATTN. FACTOR Δ SYST. WEIGHT (LBS)	UNCOOLED DISK SHIELDS					VARIABLE INTERNAL & BRIM SHIELDS				
	100	30	10	3	1	100	30	10	3	1
External Disk Shield	4200	7100	12300	18000	23300					
Add. Int. & Brim Shields						3450	6650	11950	17650	22900
Shield At Payload	0	3000	3000	3000	3000	0	3000	3000	3000	3000
Separation Distance	300	300	300	300	300	300	300	300	300	300
Basic Int. Shield	3300	3300	3300	3300	3300	3300	3300	3300	3300	3300
TOTAL	7800	13700	18900	24600	29900	7050	13250	18550	24250	29500

TABLE 12

Δ SYSTEM WEIGHT FOR 10 REM WITH 7,500 LB RESIDUAL LH₂ IN 60° TANK - 250" S.D.

PAYLOAD ATTN. FACTOR	UNCOOLED DISK SHIELDS					VARIABLE INTERNAL & BRIM SHIELDS				
Δ SYST. WEIGHT (LBS)	100	30	10	3	1	100	30	10	3	1
External Disk Shield	2600	6400	11200	16900	22100					
Add. Int. & Brim Shields						2600	6400	11200	16900	22100
Shield at Payload	0	2550	3000	3000	3000	0	2500	3000	3000	3000
Separation Distance	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
Basic Int. Shield	3300	3300	3300	3300	3300	3300	3300	3300	3300	3300
TOTAL	7200	13550	18800	24500	29700	7200	13500	18800	24500	29700

TABLE 13

Δ SYSTEM WEIGHT FOR 10 REM WITH 7,500 LB RESIDUAL LH₂ IN 60° TANK - 356" S.D.

PAYLOAD ATTN. FACTOR	UNCOOLED DISK SHIELDS					VARIABLE INTERNAL & BRIM SHIELDS				
Δ SYST. WEIGHT (LBS)	100	30	10	3	1	100	30	10	3	1
External Disk Shield	850	6000	3650	14450	19700					
Peripheral Disk or Brim Shield						900	6100	8750	14550	19750
Shield at Payload	0	0	3000	3000	3000	0	0	3000	3000	3000
Separation Distance	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600
Basic Int. Shield	3300	3300	3300	3300	3300	3300	3300	3300	3300	3300
TOTAL	7750	12900	18550	24350	29600	7800	13000	18650	24450	29650

FIGURE 29

SYSTEM WEIGHT INCREMENT FOR 10 REM
WITH VARYING PAYLOAD ATTENUATION FOR BRIM
SHIELD AND UNCOOLED DISK SHIELDS

Once again, to reduce the Δ system weight to a more desirable level, perhaps 20,000 lbs, a spacecraft attenuation of approximately 8 is needed.

E. Contributions to Crew Dose by Individual Source

The breakdown of the various contributors to the crew dose is given in Table 14. The data is normalized to unity such that comparisons can be made with other similar data.

TABLE 14

CREW DOSE COMPOSITION FOR FERRY MISSION
 CONFIGURATION WITH 60° TANK, 200" S.D., NO ENGINE SHIELDS

PVARA Direct	.280
PVARA Scatter	.326
LH ₂ Capture	.065
Nozzle Direct	.001
Nozzle Scatter	.132
Skirt Ext. Direct	.040
Skirt Ext. Scatter	.019
TEL Direct	.006
PDL Direct	.044
TIL Direct	.040
TEL Scatter	.002
PDL Scatter	.022
TIL Scatter	<u>.023</u>
TOTAL	1.000

VI. Comparison of Present LH₂ Tank Analysis with Previously Reported Results

An important part of any analysis is an understanding of the data especially when changes seem to occur between one phase of the study and the next phase. This section traces the crew dose or tank top dose data from that calculated in early 1968 and subsequently reported in Reference

6 to the 75° LH₂ tank currently being used for analysis (Table 15).

The tank top dose rate was initially calculated to be 27,300 Rem with 24,400 Rem of this value from lines and nozzle sources in March of 1968. Inclusion of a boral reduced the line sources by a little better than a factor of two and resulted in a total dose of 14,200 Rem, with the line and nozzle sources contributing 11,300 Rem of this total, as reported to SNPO in May, 1968. At that time the effect of changing the PDL material from CRES-347 to Al-7039 and the two TEL's from HAST-C to Zircalloy-2 resulted in a total dose of 7,300 Rem, 4,400 Rem of which was due to line and nozzle sources.

In a review with SNPO personnel on August 6, 1968, results of changing the propellant tank shape from the previous $\sqrt{2}$ ellipse to a 60° extended conical tank were presented. The case with the original line materials and no boral liner dropped to 21,100 Rem total (19,500 due to lines and nozzle sources). The original materials case with the boral liner dropped to 10,600 Rem (9,000 Rem from lines and nozzle sources). The case with alternate line materials dropped to 5,300 Rem (3,600 Rem from line and nozzle sources).

At the conclusion of the Joint Shielding Study in October 1968, a major recomputation of the line sources was presented in which the sources were substantially lower than the earlier calculations. Errors in the earlier line source calculations were corrected at this time. The earlier data reflected

TABLE 15

Report and Date	RN-PA-0015 29 October 1969									RN-PA-0016 13 February 1969			
Date Work Completed	Mar 68	May 68	May 68	Aug 68	Aug 68	Aug 68	Oct 68	Oct 68	Oct 68	Oct 68	Feb 69	Feb 69	Mar 69
Description of Case	√ 2 Elliptical Tank			60° Conical Tank			60° Conical Tank			60°	60°	60°	75°
	Orig.	Orig.	Alt.	Orig.	Orig.	Alt.	Orig.	Orig.	Alt.	Alt.	Alt.	Alt.	Alt.
	Mats.	Mats.	Mats.*	Mats.	Mats.	Mats.*	Mats.	Mats.	Mats.*	Mats.*	Mats.*	Mats.*	Mats.*
	No	Boral	Boral	No	Boral	Boral	No	Boral	Boral	Boral	Boral	Boral	Boral
	Liner	Liner	Liner	Liner	Liner	Liner	Liner	Liner	Liner	Liner	Liner	Liner	Liner
PVARA Direct Gamma	1610	1610	1610	1300	1300	1300	1620	1620	1620	1345	1345	772	348
PVARA Scatter Gamma							2790	2790	2790	2148	1077	902	443
LH ₂ Capture Gamma	1300	1300	1300	350	350	350	220	220	220	167	167	180	23
Nozzle Direct Gamma										3.4	3.4	2	1
Nozzle Scatter Gamma	1216	1216	1158	970	970	970	880	880	880	436	436	365	135
Skirt Ext. Direct "										190	190	109	56
Skirt Ext. Scatter "										61.2	61.2	51	57
TEL Direct Gamma										28	28	16	107
PDL Direct Gamma										211	211	121	19
TIL Direct Gamma	23200	10060	3260	18500	8010	2640	5800	2220	720	190	190	109	57
TEL Scatter Gamma										7.3	7.3	6.1	99
PDL Scatter Gamma										72	72	60	28
TIL Scatter Gamma										75	75	63	59
TOTAL GAMMA DOSE	27326	14186	7328	21120	10630	5260	11310	7730	6230	4884	3813	2756	1432
Internal Shield Weight	2500	2500	2500	2500	2500	2500	3300	3300	3300	3300	3300	3300	3300
Separation Distance	172	172	172	172	172	172	186	186	186	200	200	200	200
LH ₂ Residual	0	0	0	0	0	0	0	0	0	0	0	7500	7500
	Tank Top Detector			Tank Top Detector			Tank Top Detector			Candidate Couch Position for the Substitute Sync. Orbit Ferry Mission			

*Alternate Materials: Aluminum PDL, Zircalloy-2 TELs.

too large a ratio of total to fast neutrons. The spectrum was significantly altered in the DOT program calculations which resulted in the October data. The fast neutron flux in October was close to that predicted in the earlier studies.

During this same time period, the liquid hydrogen drainage curves were recomputed in great detail. The result of this detail analysis was no essential change in the line and nozzle time integrated dose to empty tank dose rates but a major change in the PVARA leakage data. That is the PVARA leakage dose rate was computed to be the same dose rate at the end of the run if all LH_2 was consumed. Moreover, the breakdown between PVARA direct and PVARA scattered had not changed. What change was the drainage curves as a result of several months analyses. The previous PVARA scattered drainage curve was found to be in error by a considerable amount and the PVARA direct curve by a much lesser amount. The net effect was that although the vapor only PVARA dose rate was still $2/3$ direct and $1/3$ scatter, as previously computed, the integrated doses increased from a previous PVARA total of 1300 Rem to a new total of 4400 Rem. The breakdown of PVARA contributions became 1620 Rem direct and 2790 Rem scatter.

The line and nozzle sources were 6700 Rem, 3100 Rem and 1600 Rem respectively for the original materials with no boral, the original materials with boral, and the alternate materials with boral. The overall total was 6200 Rem for this last case.

Also in October a separation distance change from 186" to 200" resulted in tank top dose changes from 6200 Rem to 4900 Rem for the case of the alternate materials with the boral liner.

Further study of the PVARA scattered dose contribution resulted in a reduction of this contribution from 2100 Rem to 1100 Rem with all other sources being unchanged. This data was presented to SNPO in February, 1969, with a total dose of 3813 Rem (1124 Rem from line and nozzle sources).

If the dose integration is terminated with 7500 lbs residual LH₂ rather than the no residual conditions of all the previous data in this section the dose drops from 3813 Rem to 2756 Rem.

When the tank bottom configuration was changed from a 60° conical shape to a 75° conical shape the dose dropped from 2756 Rem to 1432 Rem, with about equal contributions from the PVARA and lines and nozzle sources, as calculated in March, 1969.

The LH₂ secondary gamma contribution was originally computed to be 1300 Rem for the $\sqrt{2}$ elliptical tank configuration. This was reduced to 350 Rem when the tank shape was changed from the $\sqrt{2}$ elliptical bottom to a 60° extended conical bottom. This 350 Rem value was later refined to 220 Rem for the 60° configuration with a 185" separation distance from core center to the tank bottom. This later calculation resulted in a 167 Rem LH₂ capture gamma contribution with a 200" separation distance. When the LH₂ dose integration is terminated with 7500 lbs LH₂ rather than the vapor only condition this number is increased from 167 Rem to 180 Rem. Finally, a dramatic drop from 180 Rem to 23 Rem occurs when the tank bottom is changed from a 60° to a 75° conic section.

VII. Capsule Shielding

Capsule shields as defined in sections IV and V were further evaluated for attenuation from all sources for both steel and lead and for 35" radius and 60" radius shields. Radial traverses were taken at both the aft and forward couch position in the substitute synchronous orbit ferry mission (Figure 30). All analyses in this section were performed with the 75° conic bottom tank.

Figure 31 shows a comparison of the effectiveness of the various shield concepts on a per pound basis. The data for the variable internal and brim shields and the disk shield are the envelope data from Section IV. The data for the lead and steel curves are calculated from the single scatter TIL curves in Figures 19 and 20 the importance of this graph is that either the brim or the disk concepts are better shields on a per pound basis than the steel capsule shield or below 6000 lbs, than the lead shield when only one type shield is used. It must be remembered that multiple scatter in the capsule is not considered and therefore the steepness of the lead shield curve is over estimated. The capsule shield curves can only reasonably be applied for attenuations of 3 to 7. The higher attenuation of 7 is in the questionable range.

Figure 32 and 33 for lead and steel respectively show a breakdown of the various contributors to the crew dose. These data are given for a capsule shield only. Most contributors lie in a band with the nozzle direct curve below. One important aspect of this type of graph is that unless you shield against all sources the crew dose will remain undesirably high.

FIGURE 30

SUBSTITUTE SYNCHRONOUS ORBIT FERRY
MISSION PAYLOAD CONFIGURATION

The data presented in Figure 34 for a 35" capsule shield show the minimum total shield - capsule shield weights to obtain the desirable level of 10 Rem. These data are dangerously misleading. First, the calculation was to a point detector on centerline at the couch, but the astronauts are not point detectors. Second, the 35" radius shield is inadequate as seen in Figures 35-37 where neither outboard couch position is protected nor is the head of the center position. The 60" radius shield does cover all three couch positions and is adequate under the scope of this study, provided some estimate is made for shielding to protect against radiation scattering around the 60" radius disk. The steel attenuation curves are a reasonable first approximation to what a lead disk with scatter shield could weigh.

The remainder of the curves in this section show the effect of the 35" and 60" capsule shields on the crew dose at both the aft and forward couch positions as a function of radius. Figure 38 is for a 35" - 5000 lb lead shield and shows results for both the aft and forward couch positions. The centerline point detector is included in order to show graphically how misrepresentative a point detector is in this case. Figure 39 gives a breakdown of the contributors at the forward couch plane with a 35" lead shield.

Figure 40 depicts the results with and without a 60" - 14,700 lb lead shield at both couch planes. The dashed line at radii > 5 ft is for extrapolated data on the forward couch but does attain the no shield line at about 7 feet. The same type of data is presented in Figure 41 for a 19,400 lb steel shield.

Figure 42 compares the 35" - 5000 lb and 60" - 14,700 lb lead capsule shield results with a breakdown of the contributors. Also included is the no shield data for comparison. Note that this data is for the aft position only.

FIGURE 34

COMPARISON OF NRO & WANL

SHIELD WEIGHTS FOR 35" RADIUS CAPSULE SHIELD
BASED ON POINT KERNEL COMPUTER CODES

FIGURE 35

Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

FIGURE 36

Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

>1000 Rem

FIGURE 37

Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

FIGURE 39

DOSE AT FORWARD CORNER OF SUB. SYN. ORBIT FERRY MISSION
 VS. RADIAL DISTANCE FROM C. WITH 35" RADIUS LEAD CAPSULE SHIELD

- NOTES: (1) 75° Conical Tank
 (2) 7500 lbs Residual Ldg
 (3) 200" Core Center/Tank Bottom Sep. Dist.
 (4) 3300 lbs Int. Shield in PVARA
 (5) 8800 lbs Total Shield Weight
 (6) Point Kernel Scatter Code with no Scatter Surfaces Fwd of Tank Top

It should be noted that shielding at the engine provides a "cone of protection" for the payload and that a point detector for such a shield is valid because off axis detectors are in the same "cone of protection".

VIII. Effects of Brim Shield on the Engine System

The size and weight of the brim shield, as well as the internal shield, will differ with each mission. The brim shield, when present, is cooled as part of the thermodynamic cycle. As such, it will be an influence on the cycle performance. The amount of influence has been evaluated in a preliminary manner, assuming that the point of extraction of the fluid is from the pump discharge or from the dome. The more significant influence on the engine system is its effect on the dynamic behavior, especially during startup. This effect is the result of the variable internal shield causing a difference in plenum volumes as well as mass differences in the various brim shield and the internal shield combinations. The effects of these differences will be discussed in more detail below.

The steady-state influence on the system, assuming 2.4 Mw of heating in the brim shield, is fairly minor. If the coolant is from the pump discharge line, the specific impulse would actually be increased by 0.3 of a second and the turbine inlet temperature would go up 56.2°R. However, the system would probably be redesigned to maintain the turbine inlet temperature constant and thus the specific impulse would actually show a loss of about 0.3 of a second or result in chamber temperature increase of about 3°R to maintain a constant Isp level. If the brim shield is cooled from the dome, the effect on the overall system is even less than from the pump discharge. The specific impulse would drop about 0.15 of a second resulting in chamber inlet temperature increase of 1.5°R, required to maintain the same overall system Isp.

Table 16 covers the effects of brim shield on pre-conditioning. An attempt was made to evaluate what would be the effect on the engine startup of adding a large mass in the pump discharge line. Shutdown was also reviewed and

TABLE 16
EFFECT OF BRIM SHIELD ON PRECONDITIONING

WEIGHT

STAINLESS STEEL	1101 LBM
ALUMINUM	302
LITHIUM HYDRIDE	507
LEAD	4099
BORAL	<u>500</u>
TOTAL	6509 LBM

HEAT-TO-BE-REMOVED DURING PRECONDITIONING CYCLE

316K BTU's

HYDROGEN REQUIRED

600 LBM

TIME (30 PS' TANK PRESSURE)

5 MINUTES

engineering judgement at this time is that there would be an insignificant effect. The breakdown of the various parts of the brim shield is shown. These add up to a mass of 6509 lbs. The liquid hydrogen in the brim shield is not shown because that would be part of the hydrogen in the cycle and not a weight penalty.

Assuming that the material starts from ambient conditions and must be cooled to liquid hydrogen conditions, approximately 316,000 Btu's must be removed from the brim materials. If hydrogen is used to remove the stored energy, approximately 600 lbs would be required. With a driving pressure of 30 psi tank pressure, the flow rate was estimated to be approximately 2 lbs/sec for a cooldown time of approximately 5 minutes.

To summarize, the pre-conditioning cycle would go from approximately 20 seconds to 5 minutes. On a suborbital start this would result in a large loss in vehicle velocity and payload.

Thus a summary of the results of the pre-conditioning cycle as far as startup is concerned can be made. Because of the long chilldown times, a ground chilldown system would probably need to be added to the engine system. With the undesirable feature of circulating hydrogen on the test stand, it would mean that helium would probably be the fluid. The ability to remove the heat with helium is much less than with hydrogen and therefore approximately five times as much will be required. Thus, on a suborbital type mission with a brim shield, on the ground, from 3000 lbs of helium will probably be required. In a restart in flight, it is assumed the timing is not critical and therefore the chill for pre-conditioning can be performed through the engine system using liquid hydrogen. This would result in the use of an extra 600 lbs of hydrogen as a payload penalty if the time between burns is sufficient for the brim shield

to return to its ambient condition. As far as qualifying the engine system with the brim shield, because it now influences the thermodynamic cycle, it appears that it will be necessary to PFRT several versions of the NERVA engine system.

IX. Qualification Testing

Because of the perturbations associated with the present engine test stand, qualification testing of the shields will have to be accomplished in a low background facility. Such a facility would be designed to minimize the radiation contribution due to its structure. Measurements made during the XE low power and intermediate power dosimetry runs as well as calculations support this thesis.

Gamma sensitive thermoluminescent dosimeters (TLD) were located as shown in Figure 1. Nine of the indicated positions (shown circled in Figure 43) can be compared to predictions of pre-test calculations. To analyze the relative contributions from the test article (PVARA) and the facility, calculations were performed using two different methods of analysis. The first method utilized the point kernel code, QAD, the second method utilized a highly biased Monte Carlo code, FASTER. The agreement among these calculations and measurements with two different types of TLD is quite good along a radial traverse at core midplane (shown in Figure 44). The influence of the facility on the dose rate is taken into account in a rough fashion. But the approximations seem to have been quite good along this radial because of the agreement of measured and calculated data. However, in the lower thrust structure (LTS) region (Figure 45), the facility contribution was a larger perturbation on the measurement. The measured gamma dose rates scaled up to full power operation are about double the QAD predictions. Probably this indicates that the simulation of the facility was somewhat lacking. Unfortunately, the experimental data cannot resolve the facility and PVARA contributions. More sophisticated measurement techniques utilizing collimated gamma ray

FIGURE 43 -- XE-2 Dosimeter Locations

FIGURE 44

FIGURE 45

spectrometers would be required to separate the individual contributors to the total dose. The facility contribution is even more apparent along the lower surface of the external engine shield, as shown in Figure 46. Measurements on the low power dosimetry run indicate gamma dose rates about double those predicted by QAD (Figure 47).

Besides the problem of measuring radiation in such a cluttered environment, one must consider the effect of radiation heating in the test compartment. Table 17 compares the radiation heating of shields of three configurations in ETS-1.

FIGURE 46

TABLE 17

RADIATION HEATING OF SHIELDS IN ETS-1 COMPARTMENT (BTU/SEC)
(NO INTERMEDIATE SHIELD)

	<u>DISK</u>	<u>R = 37" BRIM 3,300# INT.SH.</u>	<u>R = 37" BRIM 2,800# INT. SH. W/W</u>
FLIGHT ENVIRONMENT	100 BTU/SEC	430 BTU/SEC	840 BTU/SEC
FACILITY CONTRIBUTION	250	320	320
TOTAL	350	750	1160
FACILITY CONTRB. % OF FLIGHT	250%	74%	38%

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