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WANL MASTER
PRESENTATION FOR THE
SHIELD DESIGN CRITERIA
MEETING, SNPO-C,
NOVEMBER 19 AND 20

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ABSTRACT

This report describes the WANL presentation given at the Shield Design Criteria Meeting held at SNPO, Cleveland, on November 19 and 20, 1963. The purpose of this presentation was to determine if the radiation levels outside the flight type shield were adequate for a RIFT flight. The radiation environment at 10 feet from the NRX-A2 reactor core center are given for these conditions: no shield, aluminum mockup shield, and the flight type shield. Radiation environment in the vicinity of the control drum actuator for the flight shield conditions are presented. Results of propellant heating calculations for the three conditions cited above are also given in this report.

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SUMMARY

A review of the radiation levels outside the flight shield indicates that no insurmountable development problems exist for WANL components located above the shield.

Comparison of the radiation environment at 10 feet from the NRX-A2 reactor core with the flight shield and the aluminum mockup shield showed that:

- 1) The gamma ray attenuation for both shields is essentially the same; i. e. , a factor of 20 on the shield centerline
- 2) The fast neutron attenuation on the centerline is a factor of 630 for the flight shield and a factor of 22 for the aluminum mockup shield
- 3) The extra-core gamma rays from either shield increases the total gamma ray dose rate on the centerline by about 50%.

A detailed analysis of the heat deposition in an actuator located above the flight shield showed a total of 290 watts of heat deposited.

A comparison of total integrated propellant heat deposition shows that the flight shield attenuates the energy deposition by about a factor of 16 while the aluminum mockup shield attenuates a factor of 7. Thus, the flight shield somewhat exceeds the design condition of 90% heat reduction and the aluminum shield

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does not quite meet the design condition. Typical temperature rises are 30, 2.5, and 1.4 °F for the unshielded, aluminum, and flight shields, respectively with no residual hydrogen in the tank, complete mix model, and 10.5 foot separation distance. The flight shield also eliminates the steep heating gradient in the propellant tank.

1.0 INTRODUCTION

The general purpose of the WANL presentation was to determine if the radiation levels outside the flight type shield are adequate for a RIFT flight. The topics discussed are outlined below:

- A. Geometry
- B. Radiation levels at 10 feet from the core center with no shield, an aluminum mockup shield, and a LiH-SS shield.
- C. Radiation levels at WANL components located above the flight shield.
- D. Propellant heating calculations for both 10.5 and 13.5 feet separation distances with no shield, an aluminum mockup shield, and a Li-H-SS shield.

2.0 GEOMETRY

The geometry used in this study differed in some aspects from the Standard Radiation Model (REON 2492).

- 1) No engine was included in this study.
- 2) An aluminum pressure vessel was used in place of the titanium vessel.
- 3) A new suppressor plate design was included above the core.
- 4) A General Electric actuator replaced the Bendix design.
- 5) Updated reactor core axial and radial power distributions were utilized.
- 6) Additional sources of secondary gamma rays were considered.

The reactor power distributions and distributions of secondary gamma rays may be obtained in Reference 1.

Figure 1 shows a cross section view of the flight shield.

Appropriate dimensions are given in the drawing. The LiH pellets, steel spacers and boronated steel are encapsulated in stainless steel tubing. Seven capsules are bundled together to form a module. Each module is connected to the top and bottom support plates by a steel pin arrangement. The capsules on the centerline are 12.6 inches in length; at the outer periphery, the capsules are 6 inches in length. The majority of the capsules have a 5/8" diameter. Some capsules near

baffles have a 9/16" diameter. About 4900 capsules comprise the shield which weighs 2400 lbs. This shield was designed to reduce the radiation heating in the liquid hydrogen propellant by a factor of ten.

No picture of the aluminum mockup shield is presented due to its simplicity. This shield, to be used in the NRX-A2 Block I reactor tests, consists of an aluminum block, is 14 inches thick on the centerline. Approximately 600, 1/2" diameter holes are drilled in the aluminum block for coolant passages.

Figure 2 illustrates the tank geometry used in this study. The two separation distances shown in Figure 2 correspond to the TVT and TVC engine systems. Tank heating calculations were performed for three conditions; no shield, the aluminum mockup shield, and the LiH-SS shield. (Results of the calculations are discussed in Section 5.)

3.0 RADIATION LEVELS AT 10 FEET FROM THE CORE CENTER

Figure 3 illustrates the total gamma ray dose rate at 10 feet as a function of angle for the unshielded and flight shield condition. The orientation of the angle is shown in Figure 3. The unshielded geometry is defined to include the core and reflectors, radially, and the core, ~~suppressor~~ plate, and the aluminum core support plate, axially. These gamma ray dose rates include contributions due to both core gamma rays and those gamma rays born in regions outside the reactor core (extra-core gamma rays). The centerline attenuation ($\alpha' = 0^\circ$) is a factor of 20 for the flight shield. Beyond about a 50° angle, the shield no longer attenuates the gamma or neutron radiation.

All data presented in this report are for an NRX-A2 reactor operating for 20 minutes at 1120 MW (thermal).

Figure 4 is similar to Figure 3 except that the core gamma rays and extra-core gamma rays are plotted separately. For the unshielded case, extra-core gammas do not appear to contribute significantly to the total dose rate. In the shielded case, however, the core gamma rays and extra-core gamma rays are about equal from $\alpha' = 0^\circ$ to $\alpha' = 25^\circ$. Beyond that angle, the core gamma ray dose rate increases considerably due to the geometry effect of these gammas by-passing the shield.

Figure 5 illustrates the relative importance of the extra-core gamma ray sources considered in this study for two angles, namely, $\alpha' = 0^\circ$ and 45° . With 100 per cent equalling the total extra-core gamma rays, these data indicate that at 0° ,

about 54% of the extra-core gamma ray dose rate is coming from the shield. At 45° , due to the geometry effect, the beryllium reflector is the most significant contributor.

Figure 6 illustrates the total gamma ray dose rate at 10 feet as a function of angle for the unshielded and aluminum shield condition. Again, these gamma ray dose rates include contribution due to both core gamma rays and those gamma rays born in regions outside the active core. The centerline attenuation ($\alpha = 0^\circ$) is a factor of 17 for the aluminum mockup shield.

Figure 7 illustrates the core gamma ray dose rates and the extra-core gamma ray dose rates for the aluminum shielded condition. The unshielded data are repeated for convenience. The extra-core gamma rays for this shield are about 10% higher than for the flight shield.

Figure 8 illustrates the relative importance of the extra-core gamma ray sources for two angles, namely, $\alpha = 0^\circ$ and 45° . At $\alpha = 0^\circ$, about 65% of the extra-core gamma dose is due to the aluminum shield itself. At 45° , the data are similar to that for the flight shield.

The gamma ray dose rates were calculated using the point kernel program 14-0². The extra-core gamma ray sources were calculated by using the 51 group diffusion code, P1MG, to obtain reaction rates (capture and inelastic scattering gamma rays). The reaction rates from the 51 group data were obtained at one point in each region of interest from either the axial or radial one-dimension diffusion calculation. The spatial variation of the reaction rates in each region of interest was obtained by using a four group two-dimension diffusion calculation (Program CURE⁴).

The four group data were normalized to the 51 group data at the appropriate point in each region. This normalization was performed at that point nearest the reactor-core in each region. A detailed description of the methods of analysis are given in Reference 1.

Figure 9 shows a comparison of two methods of calculating core gamma ray dose rates at 10 feet from the core center as a function of angle for the unshielded and flight shield condition. The first method is the familiar point kernel method using Program 14-0. The second method utilized the equivalent point source output data from Monte Carlo Program 18-0⁵. The general agreement is within a factor of 2 to 3 for the unshielded condition.

Figure 10 shows the fast neutron flux ($E \geq 1$ Mev) at 10 feet from the center of the core as a function of angle for the unshielded and flight shield condition. The centerline attenuation ($\alpha = 0^\circ$) for this shield is a factor of 630. Similar data for the aluminum mockup shield are presented in Figure 11. The centerline attenuation for this shield is a factor of 22. The fast neutron fluxes were calculated using the neutron spectra option in Program 14-0. The 14-0 fluxes were normalized at the surface of the assembly to two-dimensional diffusion flux data from Program CURE.

4.0 RADIATION LEVELS AT WANL COMPONENTS

Twelve actuators are located directly above the pressure vessel. The geometrical mockup of a General Electric actuator used in this study is presented in Figure 12. The five regions illustrated in Figure 12 mockup the following components: Region 1 - pressure vessel coupling; Region 2 - servo-valve, torquemotor, etc. ; Region 3 - piston-rack; Region 4 - shaft; and Region 5 - potentiometer. Each actuator weighs 15 lbs.

The radiation environment in the actuator, shown in Figure 13, is for the flight shield condition. Heating rates, gamma ray fluxes (from core gamma rays and extra-core gamma rays), and fast neutron fluxes ($E > 1$ Mev) are presented. (Note: the value of $H = 0.57$ should read $H = 0.057$.) The total heat absorbed in the actuator (Regions 2, 3, 4, and 5 - Figure 12) is 290 watts, or approximately 19 watts/lb aluminum.

5.0 PROPELLANT HEATING CALCULATIONS

Calculations have been made of the integrated heating in the hydrogen propellant and resultant temperature rise in the hydrogen leaving the propellant tank for two separation distances and 3 different conditions. The two distances are 10.5 and 13.5 feet which, correspond to the TVT (Thrust Vector Trim) system and the TVC (Thrust Vector Control) system, respectively. The three conditions considered are unshielded reactor, the reactor with the aluminum mockup shield, and the reactor with the aluminum mockup shield, and the reactor with LiH-SS shield.

The calculations were made with the Westinghouse Codes TIC-TOC and TOE⁶ with radiation sources given in Section 2. The geometry for these calculations as shown in Figure 2 was obtained from the standard radiation model.

The gamma energy fluxes including all secondary gamma sources in the reactor and shield were calculated by use of the 14-0 code at 10' from the reactor core center. These fluxes, which are actually uncollided gamma fluxes times a buildup factor, were then converted to equivalent point sources in each of 3 gamma energy groups of average energy 1, 3, and 6 Mev by multiplying the fluxes by $4\pi r^2$ where r is 10' or 305 cm. These fluxes and the resultant source strengths were calculated as a function of polar angle measured about the reactor-tank ϵ axis in 5° increments out to 30° , and at 45° . Similarly, neutron fluxes which were normalized to CURE calculated fast neutron fluxes at the surface of the reactor or shield, were calculated at 10 feet from the reactor by the 14-0 code using the neutron spectra option. The 14-0 spectra were

obtained using either water moments data fits or LiH moments data fits in the 14-0 code. The water data was used for both the unshielded and Al shield calculations. The fast neutron fluxes in each of 3 energy group ranges 1, 3, and 7 mev, and for the same polar angles as for the gamma rays, were converted to equivalent point sources by multiplying by $4\pi r^2$. These source strengths are shown in Figures 14 and 15 for the unshielded reactor and for the Al mockup and LiH shields.

These sources were used as input to the TIC-TOC code to calculate heating distributions, integrated heating, and temperature rise of the hydrogen leaving the propellant tank due to fast neutron and reactor gamma ray sources. Intermediate ($1.86 \text{ ev} > E > 0.4 \text{ Mev}$) and thermal fluxes ($E > 1.86 \text{ ev}$) were obtained directly from the CURE output. TOE, the code which calculates secondary gamma source heating due to captures in the liquid hydrogen, has been modified to include incident neutron energies in the intermediate and thermal energy ranges as well as the fast neutron range which it formerly treated.

The results of the calculations for the two different separation distances and three different conditions are shown in Tables 1 and 2 for separation distances of 10.5 and 13.5 feet, respectively. Temperature rise of the last hydrogen leaving the tank are also given for two fluid flow models, no mix and complete instantaneous mix, and for no hydrogen left in the tank or for 5' of hydrogen left in the bottom of the tank. Temperature rise of the last hydrogen leaving the tank is a function of the hydrogen remaining since the residual hydrogen acts as a shield as long as it remains in a liquid state. At the present time, the mission which the NERVA vehicle must accomodate

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is not well defined and hence it is not known how much, or if any, residual propellant will be required.

Hence, the temperature rises given for the two levels of residual hydrogen are intended to show trends rather to give numbers for design conditions.

A comparison of total integrated heating values in Tables 1 and 2 show that the LiH shield attenuates the energy deposition in the tank by about a factor of 16 while the Al mockup shield attenuates a factor of about 7. Thus the LiH shield exceeds the design conditions of 90% energy removal while the Al mockup does not quite meet the design condition.

Typical temperature rises are 30, 2.5, and 1.4 °F for the unshielded, Al mockup, and LiH shields, respectively with no residual hydrogen left in the tank, complete mix model, and 10.5 foot separation distance. Temperature rises with 5' residual hydrogen with other conditions the same are 10, 1.2, and 0.72 °F for the unshielded, Al mockup, and LiH shield cases respectively. Thus, with 5' of residual hydrogen, the Al mockup can approximately equal the temperature rise with the LiH shield for no residual hydrogen. The additional weight penalty involved, however, is 3525 lbs.

It should also be noted that the integrated heating in the shield is more than twice as great in the LiH shield as in the Al mockup. In the original design of the shield, a large amount of heating in the shield was desirable since this heat was to be extracted and used in powering a turbine. Since the design has now changed from the heated bleed system described above to the hot bleed system, this is no longer true.

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The total heating density in the hydrogen propellant as a function of position in the tank for the unshielded, Al mockup, and LiH shield cases are shown in Figures 16, 17, and 18, respectively.

In comparing these heating rates, the following observations can be made: 1) The peak heating density for the no shield case is about 2.5×10^{-3} BTU/in³ - sec. followed by a relatively steep gradient near the bottom of the tank caused by predominantly neutron heating. 2) The peak heating for the Al mockup case is about 5.5×10^{-4} BTU/in³ - sec. followed by a gradient which is somewhat less steep than for the no-shield case but still indicating a predominance of neutron heating near the bottom of the tank. 3) The peak heating density for the LiH shield case is about 5.5×10^{-5} BTU/in³ - sec which occurs near the corner at the side of the tank instead of at the bottom of the tank. In this case, the steep gradient due to neutron heating has essentially been eliminated.

Steep gradients due to neutron heating in the bottom of the tank could be important in shield criteria selection depending on the fluid mixing model and the amount of residual hydrogen left in the propellant tank.

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CROSS SECTION VIEW OF FLIGHT SHIELD

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TOTAL GAMMA RAY DOSE RATE VS ANLGE - 10 FEET FROM THE CORE CENTER

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CORE GAMMA RAY AND EXTRA-CORE GAMMA RAY DOSE RATE
VS ANGLE - 10 FEET FROM THE CORE CENTER

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EXTRA-CORE GAMMA RAY SOURCE	% OF TOTAL EXTRA-CORE GAMMA RAY DOSE RATE	
	$\alpha = 0^\circ$	$\alpha = 45^\circ$
BORONATED STEEL	26.0	3.2
PINS AND END CAPS	22.0	1.4
LiH STEEL	6.6	0.7
Be REFLECTOR	8.3	59.0
TITANIUM SUPPORT STRUCTURE	6.3	6.1
ACTUATOR SHAFT	3.7	2.8
PRESSURE VESSEL	1.9	14.8
ALUMINUM CORE SUPPORT PLATE	18.6	0.9
LATERAL SUPPORT	1.7	9.1
CLUSTER PLATE	4.9	2.0
TOTAL	100.0	100.0

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CORE GAMMA RAY AND EXTRA-CORE GAMMA RAY DOSE RATES
 (ALUMINUM MOCKUP SHIELD)

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EXTRA-CORE GAMMA RAY SOURCE	% TOTAL EXTRA-CORE GAMMA RAY DOSE RATE	
	$\alpha = 0^\circ$	$\alpha = 45^\circ$
ALUMINUM SHIELD	64.7	8.4
Be REFLECTOR	7.1	54.3
TITANIUM SUPPORT STRUCTURE	4.2	6.0
ACTUATOR SHAFT	2.3	2.7
PRESSURE VESSEL	2.1	13.8
ALUMINUM CORE SUPPORT PLATE	14.4	4.2
LATERAL SUPPORT	1.6	8.4
CLUSTER PLATE	3.6	2.2
TOTAL	100.0	100.0

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COMPARISON OF PROGRAM 14-0 AND 18-0 CORE GAMMA RAY DOSE RATE
 AT 10 FEET FROM THE CORE CENTER

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FAST NEUTRON FLUX (E>1 MEV) VS ANGLE - 10 FT FROM THE CORE CENTER

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ACTUATOR GEOMETRICAL CONFIGURATION FOR PROGRAM 14 - 0

	PREPARED BY	APPROVED BY	CURVE NO

REFERENCE

NRX-A ACTUATOR RADIATION ENVIRONMENT

	PREPARED BY	APPROVED BY	CURVE NO.

563810A

TOTAL HEATING DENSITY VS
DISTANCE ABOVE BOTTOM OF PROPELLANT TANK FOR UNSHIELDED REACTORS

TOTAL HEATING DENSITY VS
 DISTANCE ABOVE BOTTOM OF PROPELLANT TANK FOR ALUMINUM SHIELD

TOTAL HEATING DENSITY VS
DISTANCE ABOVE BOTTOM OF PROPELLANT TANK FOR LIH SHIELD

TABLE 1

COMPARISON OF HEATING CALCULATIONS IN PROPELLANT TANK AND SHIELD
 TANK HEATING - Separation Distance = 10.5 Ft.

	Integrated Heating (MW)			Temperature Rise (°F)		
	Neutrons	Gammas	Sec. Gammas In H ₂	Total	Complete Mix	No Mix
No Shield	0.169	0.615	0.24	1.03	0	29.7
					5'	10.2
Al Shield	.0124	.0837	0.06	0.156	0	2.46
					5'	1.16
LiH Shield	.00196	.0585	0.0028	0.063	0	1.38
					5'	0.72

Total Shield Heating (MW)

Al - 1.2

LiH - 2.9

Wt. of 5 Ft. H₂ in Bottom of Tank = 3525 lbs.

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TABLE 2

COMPARISON OF HEATING CALCULATIONS IN PROPELLANT TANK AND SHIELD
TANK HEATING - Separation Distance = 13.5 Ft.

	Integrated Heating (MW)				Temperature Rise (°F)	
	<u>Neutrons</u>	<u>Gammas</u>	<u>Sec. Gammas In H₂</u>	<u>Total</u>	<u>Complete Mix</u>	<u>No Mix</u>
No Shield	0.136	0.510	0.19	0.84	0	29.0
					5'	8.3
Al Shield	.00855	.0538	0.0475	.120	0	2.01
					5'	0.75
LiH Shield	.000884	.0369	0.0013	.039	0	0.95
					5'	0.44

Total Shield Heating (MW)

Al - 1.2

LiH - 2.9

Weight of 5 Ft. of H₂ in Bottom of Tank = 3525 lbs.