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Privy Roof Mounted

Shield Proposal

MASTER

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NRX A TEST ASSEMBLY

FIG 1

SUMMARY

The proposed shield is required on the NRX test car in order to alleviate the following problems due to radiation heating and activation.

1. The total radiation doses, predicted from experimental data obtained from the NRX-A2 tests, indicate that levels will be above the damage threshold for certain critical components of the test assembly. These components are the actuator seals, hydraulic fluid and electronic cables which have a damage threshold of approximately 5×10^6 to 10^7 rads. It has been predicted that these dose levels will be reached when more than 30 minutes of NRX full power run-time is accumulated on Test Assembly (See Table I).
2. The Test Cell A facility has been activated by the NRX-A2 tests to an extent which would indicate that this activation could become a major problem as a result of high accumulated full power reactor tests. Present radiation readings of 10 to 25 mr/hr in the test pad - test cell area are a result of the NRX-A2 operations. The extension of the privy roof shadow shield in the close proximity of the reactor will reduce by approximately 90 per cent the radiation emitted by the reactor in the 135° sector that is shielded. This will appreciably reduce the test cell wall activation as well as other parts of the facility. The proposed shield on the NRX-A3, considering only 20 minutes of full power run time, would reduce facility activation considerably.
3. Since the state-of-the-art of shield design cannot be expected to correlate with experimental results better than a factor of two, it would greatly enhance the design information if this shield design could be evaluated prior to exposing it to more than 30 minutes of run time.
4. In addition, the proposed shield represents a straight forward design which gives maximum flexibility in test car plumbing design. It also prevents the problems relative to hydrogen gas accumulation since this is impossible, and fires previously experienced will not effect the water-cooled aluminum shield. In addition, design problems relative to component shielding will be eliminated.

RADIATION EFFECTS CONSIDERATIONS

MATERIAL	DESIRED UPPER DOSE (RADS)	NRX-A OPERATION TOTAL DOSE (RADS)		
		20 MIN	30 MIN	60 MIN
SEAL - .30 GRAPHITED TEFLON	1×10^6	3.33×10^6	5×10^6	1×10^7
HYDRAULIC LINE AND FLUID (MIL H-5606)	5×10^6	6.66×10^6	1×10^7	2×10^7
SEALING RING ADIPRENE C	1×10^8	6.66×10^6	1×10^7	2×10^7
"O" RING SILICONE BASE	1×10^7	6.66×10^6	1×10^7	2×10^7
"O" RING NEOPRENE BASE	1×10^7	6.66×10^6	1×10^7	2×10^7
CABLING POLYOLEFIN	1×10^8	3.33×10^6	5×10^6	1×10^7

TABLE I

INTRODUCTION

This document has been compiled to demonstrate the need for an extension to the shadow shield of the NRX Test Car Privy Roof; and to propose a design concept which WANL and ACF considers a practical solution. As a result of radiation dose measurements taken during the NRX-A2 tests, it has been projected that full power runs accumulating beyond 30 minutes would cause total radiation doses to exceed that allowable within the shadow of the privy roof.

Local shielding of key components results in many separate shielding problems which can be eliminated by shielding the source. Therefore, WANL and ACF is proposing a right cylindrical section (Privy Roof Mounted Shield) which will be an addendum to the existing shadow shield (Privy Roof) and effect a reduction in total radiation dose accumulated by critical components on the test car.

Since the radiation is absorbed by the shield relatively close to the source the shield also is effective in reducing the activation of the permanent facilities as well.

A 135° sector of a cylindrical shield should be chosen for installation on the next possible NRX reactor test in order to experimentally evaluate the problems associated with this design. This 135° sector also effects the maximum protection of the test car with the minimum changes of the test car plumbing. The radiation protection afforded is shown in Table II.

Further information from actual NRX operations and more precise analyses may indicate a need to modify this 135° sector shield design to adequately control the radiation dose and activation problems associated with 60 minutes of accumulated full power time.

Table III shows the residual activity at the Test Cell A reactor pad area as it existed on December 15, 1964. It is concluded that this activity is due to NRX-A2 neutron activation since swipes from these areas indicate that no external contamination exists.

INTEGRATED DOSE (N&γ, RADS - CARBON) FOR FULL POWER NRX-A RUNS

AT VARIOUS LOCATIONS

LOCATION	20 MIN RUN		30 MIN RUN		60 MIN RUN	
	WITHOUT SHIELD	WITH 135° SHIELD	WITHOUT SHIELD	WITH 135° SHIELD	WITHOUT SHIELD	WITH 135° SHIELD
TEST CELL WALL AT CORE MIDPLANE	17.7 (6)	.634 (6)	26.6 (6)	.951 (6)	53.2 (6)	1.90 (6)
12 FT BELOW CORE MIDPLANE	9.13 (6)	.211 (6)	13.7 (6)	.316 (6)	27.4 (6)	.633 (6)
EDGE OF PRIVY AT 12 FT BELOW CORE MIDPLANE	2.87 (6)	.157 (6)	4.31 (6)	.236 (6)	8.62 (6)	.471 (6)
INSIDE PRIVY AT 12 FT BELOW CORE MIDPLANE	11.2 (5)	1.03 (5)	17.3 (5)	1.52 (5)	34.7 (5)	3.04 (5)
REAR OF TEST CAR AT 12 FT BELOW CORE MIDPLANE	5.56 (6)	4.63 (6)	8.35 (6)	6.95 (6)	16.7 (6)	13.9 (6)

TABLE II

TEST CELL A RADIATION LEVELS (MR/HR)

(NRX-A2 TEST ASSEMBLY REMOVED)

LOCATION	DATE	
	10/31/64	12/15/64
METAL CHANNELS IN TEST CELL WALL EAST FACE	50-60	20-25
TEST CELL WALL AREA AROUND PROJECTION OF THE CORE CENTER	20	10
TEST CELL AREA APPROXIMATELY 10 FT. ABOVE PROJECTION OF CORE CENTER	75-100	-
PIPING AND FIXTURES ON WALL	30-60	20-50
TEST CELL WALL AREA AROUND TEST CELL/TEST CAR PLUG INTERFACE	30-90	40
TEST PAD AREA DIRECTLY BELOW TEST ASSEMBLY	20	8-9
TEST CAR RAILS	20	9
SHED RAILS	20-25	15-20
TEST PAD (GENERAL AREA)	10-20	5-10
TEST PAD FIXTURES		
NEUTRON ALARM BOX	80	40
FLOOD LIGHTS (26' FROM REACTOR)	20-30	30

TABLE III

APPROACH

1. Nuclear Considerations

In order to understand and interpret measurements made on the test car and under the privy roof during KIWI and NRX-A2 tests, and hence increase confidence in shield design calculations, analyses were performed without the proposed shield in place. The components considered in the nuclear analysis were: gamma scatter off the cell wall and pad, gamma capture in the cell wall and privy roof, neutron scatter off the cell wall and pad, neutron air scatter, and direct gamma and neutrons. Separate contributions to the total calculated gamma dose rate are shown in Figure 2 and the contributions to the total calculated neutron flux are shown in Figure 3. These calculations can be compared with the measured values which appear in the same figures. The calculated gamma dose rates thus agree to within a factor of two at all locations where test data is available. Similar calculations of the neutron flux > 1.0 mev are shown to be about four times higher than measured neutron fluxes > 2.9 mev as obtained from nickel foil data during the NRX-A2 test. However, the ratio of flux greater than 1.0 mev to flux greater than 2.9 mev has been calculated to range from four to eight at positions near the pressure vessel surface and hence the calculated values agree to within a factor of two of the experimental values.

Further comparison of NRX-A2 and KIWI data normalized to full power conditions are shown in Table VIII. Again the comparison of measured and calculated gamma and neutron doses is within a factor of two at all locations where data is available. Hence, it is believed that the model used to calculate doses with the shield in place is reasonably correct.

The shield design has, to this date, been evaluated in terms of:

- a. direct attenuation of gamma rays and neutrons incident on the test cell wall,
- b. indirect radiation by-passing the shield and reaching various locations on the test car and under the privy roof, and
- c. secondary gamma originating in the privy roof.

The generation of secondary gamma rays in the shield was also considered. In addition, that portion of the radiation which is attenuated by the shield and which reaches these locations by indirect means, such as by scatter off the test cell wall or by capture gammas produced in the cell wall was also evaluated. The several radiation components considered in this analysis are more clearly shown in Tables IV through VII.

A description of the method used to calculate the wall and pad scattering and the capture gamma produced in the cell wall is given in Appendix I.

The neutron fluxes used to determine the secondary gamma sources for gammas produced in the shield and in the privy roof were obtained by use of the DTK one dimensional transport code with Mill's 18 group cross section library. The shield was represented explicitly in a one dimensional radial mock-up with the roof immediately adjacent to the dome end of the reactor. Using the resulting 18 group fluxes obtained from the DTK problems, absorption rates were calculated by material as a function of radial position in the shield and as a function of axial position in the privy roof. Absorption rates were then converted to gamma source strengths by multiplying the mev/absorption for each of 13 gamma energy groups. These sources were adjusted for the true location of the core by the inverse square law.

The axial source distribution in the shield and radial distribution in the privy roof were assumed to follow the fast flux incident on the shield as presented in WANL-TNR-128. These sources were then input to a 14 - 0 point kernel calculation to determine the secondary contribution to the gamma dose at the various locations under the privy roof and on the test car. The contribution of these sources are given in Tables IV to VII and the privy roof capture contribution to the unshielded case is shown in Figure 2.

Thus the effective attenuation of gammas in the shield is about 30 while that of the fast neutrons is 25 and that of thermal neutrons is a factor of 10,000.

The overall dose attenuation below the privy roof and on the test cell wall is on the order of 15 - 25. This ratio can be found as a function of distance from the cell wall by comparing the unshielded and shielded doses in Figure 4. The effect of increasing the subtended angle of the shield may be seen by comparing the 120, 135, 150 and 360 degree shield cases shown in Figure 5.

2. Vertical Shield Description

Perspective drawings of the proposed radiation shield mounted on the test car and the shield alone are shown in Figures No. 1 and 6, respectively. A detail design layout of the proposed shield is shown on WANL Dwg. 711J187.

Basically the shield is a water-cooled, partial right-cylindrical-shaped aluminum weldment that is approximately nine inches in thickness, 117-1/2 inches high, subtends a 135° angle and weighs approximately 21,500 pounds. It consists of three-quarter inch aluminum plates, three-sixteenth inch boral plates and approximately 16,500 pounds of nickel plated steel spheres (See Figure No. 8). The shield can easily be remotely removed from the test car in the R-MAD building

by the 24-ton crane and the overhead manipulator adapted tools. Also, in order to permit reusage of the shield within a short period of time, it is designed with the capability of remote and/or manual removal of the steel spheres.

The shield will be positioned on the front side of the test car ($WANL = 120^\circ$) with its inside radius being approximately 47 inches from the reactor vertical centerline. It is attached to the test car privy roof, extends as high as the pressure vessel cylinder/nozzle interface (to accommodate either an AGC or Rocketdyne RN-6 nozzle) and is nearly symmetrical about the test car centerline. The shadow which the shield casts upon the front face of the test cell wall is shown in Figure No. 7.

Primarily, the shield is supported by two of the four 8-inch aluminum H-beams of the privy structure. The added shield weight on the test car will increase the front and rear four-wheel rail truck-weight distribution from 67 and 33 per cent, respectively to 67.5 and 32.5 per cent, respectively. This added weight, however, does not require any counterweight modifications for adequate test car counterbalance.

The shield is designed such that the existing cooling water capabilities of 475 gallons per minute at 80 psig will provide adequate cooling for all shield components. Calculations have indicated that the shield water temperature rise will be approximately 50°F .

A stress analysis of the shield has indicated that the burst pressure is approximately 200 psig. In addition, the shield can withstand wind loadings up to 100 miles per hour without any means of attachment to the privy roof and not topple. As previously mentioned, however, it will be attached to the privy roof.

COMPARISON OF MEASURED, PREDICTED, AND CALCULATED GAMMA DOSE RATE UNDER TEST PLANT CONDITIONS AND TEST CAR	CURVE NO	INDEX NO
NORMALIZATION TO FULL POWER	Figure 2

FAST NEUTRON FLUX WITH ENERGIES GREATER THAN 1 MEV
UNDER THE PRIVY ROOF SHIELD NORMALIZED TO FULL POWER

CURVE NO

INDEX NO

Figure 3

COMPARISON OF DOSE RATES UNDER PRIVY ROOF AT A CAR LOCATION WITH AND WITHOUT WALL CONCEPTUAL DESIGN	CURVE NO	INDEX NO
	Figure 4

FIG 5 RADIATION LEVELS AT VARIOUS TEST CAR LOCATIONS

(RADS-CARBON HR-1 NORMALIZED TO FULL POWER)

RADIATION LEVELS AT TEST CAR LOCATION NO. 1

(RADS - CARBON HR⁻¹ NORMALIZED TO FULL POWER)

RADIATION COMPONENT	NO SHIELD	120° SHIELD	135° SHIELD	150° SHIELD	360° SHIELD
WALL CAPTURES FROM UNSHIELDED AREAS SHIELDED AREAS	28 (5)	.998 (5)	.672 (5)	.349 (5)	.349 (5)
GAMMA SCATTER FROM UNSHIELDED AREAS SHIELDED AREAS	Neg. Neg.	Neg. Neg.	Neg. Neg.	Neg. Neg.	Neg. Neg.
NEUTRON SCATTER FROM UNSHIELDED AREAS SHIELDED AREAS	Neg. Neg.	Neg. Neg.	Neg. Neg.	Neg. Neg.	Neg. Neg.
DIRECT GAMMAS	126 (5)	126 (5)	126 (5)	126 (5)	.461 (5)
DIRECT NEUTRONS	100 (4)	100 (4)	100 (4)	100 (4)	.958 (4)
VERTICAL SHIELD SECONDARY GAMMAS	-	Neg.	Neg.	Neg.	1.85 (5)
PRIVY ROOF SECONDARY GAMMAS	25.5 (4)	25.5 (4)	25.5 (4)	25.5 (4)	.440 (4)
VERTICAL SHIELD SECONDARY GAMMAS (SCATTER)	-	Neg.	Neg.	Neg.	Neg.
TOTAL	16.7 (6)	13.9 (6)	13.9 (6)	13.9 (6)	.280 (6)

TABLE IV (SEE FIGURE NO. 5)

RADIATION LEVELS AT TEST CAR LOCATION NO. 2
(RADS - CARBON HR⁻¹ NORMALIZED TO FULL POWER)

RADIATION COMPONENT	NO SHIELD	120° SHIELD	135° SHIELD	150° SHIELD	360° SHIELD
WALL CAPTURES FROM UNSHIELDED AREAS	28.5 (5)	1.48 (5)	.742 (5)	-	-
SHIELDED AREAS	-	5.69 (4)	5.83 (4)	5.98 (4)	5.98 (4)
GAMMA SCATTER FROM UNSHIELDED AREAS	35.4 (4)	6.73 (4)	5.33 (4)	4.10 (4)	-
SHIELDED AREAS	-	4.25 (3)	4.79 (3)	5.33 (3)	5.18 (3)
NEUTRON SCATTER FROM UNSHIELDED AREAS	22.0 (4)	4.46 (4)	3.89 (4)	3.33 (4)	-
SHIELDED AREAS	-	6.84 (3)	7.88 (3)	8.93 (3)	7.54 (3)
DIRECT GAMMAS	7.74 (3)	7.74 (3)	7.74 (3)	7.74 (3)	7.74 (3)
DIRECT NEUTRONS	9.86 (2)	9.86 (2)	9.86 (2)	9.86 (2)	9.86 (2)
VERTICAL SHIELD SECONDARY GAMMAS	-	1.31 (4)	1.31 (4)	1.31 (4)	1.31 (4)
PRIVY ROOF SECONDARY GAMMAS	3.90 (4)	3.70 (4)	3.70 (4)	3.70 (4)	3.70 (4)
VERTICAL SHIELD SECONDARY GAMMAS (SCATTER)	-	7.44 (3)	7.44 (3)	7.44 (3)	7.44 (3)
TOTAL	34.7 (5)	3.94 (5)	3.04 (5)	2.15 (5)	1.39 (5)

TABLE V (SEE FIGURE NO. 5)

RADIATION LEVELS AT TEST CAR LOCATION NO. 3
(RADS - CARBON HR⁻¹ NORMALIZED TO FULL POWER)

RADIATION COMPONENT	NO SHIELD	120° SHIELD	135° SHIELD	150° SHIELD	360° SHIELD
WALL CAPTURES FROM UNSHIELDED AREAS	7.45 (6)	.348 (6)	.174 (6)	-	-
SHIELDED AREAS	-	.142 (6)	.144 (6)	.145 (6)	.145 (6)
GAMMA SCATTER FROM UNSHIELDED AREAS	7.02 (5)	.680 (5)	.508 (5)	.333 (5)	-
SHIELDED AREAS	-	.095 (5)	.099 (5)	.102 (5)	.103 (5)
NEUTRON SCATTER FROM UNSHIELDED AREAS	4.25 (5)	.367 (5)	.307 (5)	.247 (5)	-
SHIELDED AREAS	-	.165 (5)	.170 (5)	.174 (5)	.174 (5)
DIRECT GAMMAS	1.19 (4)	1.19 (4)	1.19 (4)	1.19 (4)	1.19 (4)
DIRECT NEUTRONS	3.71 (3)	3.71 (3)	3.71 (3)	3.71 (3)	3.71 (3)
VERTICAL SHIELD SECONDARY GAMMAS	-	1.95 (3)	1.95 (3)	1.95 (3)	1.95 (3)
PRIVY ROOF SECONDARY GAMMAS	2.35 (4)	1.18 (4)	1.18 (4)	1.18 (4)	1.18 (4)
VERTICAL SHIELD SECONDARY GAMMAS (SCATTER)	-	1.47 (4)	1.47 (4)	1.47 (4)	1.47 (4)
TOTAL	86.2 (5)	6.65 (5)	4.71 (5)	2.75 (5)	2.15 (5)

TABLE VI (SEE FIGURE NO. 5)

RADIATION LEVELS AT TEST CAR LOCATION NO. 4
(RADS - CARBON HR⁻¹ NORMALIZED TO FULL POWER)

RADIATION COMPONENT	NO SHIELD	120° SHIELD	135° SHIELD	150° SHIELD	360° SHIELD
WALL CAPTURES FROM UNSHIELDED AREAS	12.8 (6)	.310 (6)	.155 (6)	-	-
SHIELDED AREAS	-	1.65 (5)	1.65 (5)	1.66 (5)	1.66 (5)
GAMMA SCATTER FROM UNSHIELDED AREAS	44.6 (4)	2.74 (4)	2.39 (4)	2.03 (4)	-
SHIELDED AREAS	-	6.34 (3)	6.16 (3)	5.98 (3)	6.66 (3)
NEUTRON SCATTER FROM UNSHIELDED AREAS	33.9 (4)	1.99 (4)	1.71 (4)	1.44 (4)	-
SHIELDED AREAS	-	1.81 (4)	1.18 (4)	1.19 (4)	1.22 (4)
DIRECT GAMMAS	126 (5)	.461 (5)	.461 (5)	.461 (5)	.461 (5)
DIRECT NEUTRONS	1000 (3)	9.58 (3)	9.58 (3)	9.58 (3)	9.58 (3)
VERTICAL SHIELD SECONDARY GAMMAS	-	1.85 (5)	1.85 (5)	1.85 (5)	1.85 (5)
PRIVY ROOF SECONDARY GAMMAS	255 (3)	4.40 (3)	4.40 (3)	4.40 (3)	4.40 (3)
VERTICAL SHIELD SECONDARY GAMMAS (SCATTER)	-	9.37 (3)	9.37 (3)	9.37 (3)	9.37 (3)
TOTAL	274 (5)	8.01 (5)	6.33 (5)	4.73 (5)	4.39 (5)

TABLE VII (SEE FIGURE NO. 5)

COMPARISON OF MEASURED AND CALCULATED DOSE RATES NORMALIZED
TO FULL POWER AT VARIOUS LOCATIONS

LOCATION	GAMMA DOSE RATE (RADS-CARBON/HR)			NEUTRON DOSE RATE (RADS-TISSUE/HR)		
	MEASURED		CALCULATED	MEASURED		CALCULATED
	NRX-A2 ^(a)	KIWI		NRX-A2 ^(b)	KIWI	
TEST CELL WALL AT CORE MIDPLANE	5.60 (7)	4.11 (7) ^(c)	5.04 (7)	-	3.44 (7) ^(c)	1.92 (7)
12 FT. BELOW CORE MIDPLANE	1.56 (7)	-	2.74 (7)	-	-	.925 (7)
EDGE OF PRIVY AT 12 FT. BELOW CORE MIDPLANE	-	.569 (7) ^(d)	.862 (7)	-	.180 (7) ^(d)	.304 (7)
	1.19 (7)	-	-	-	-	-
INSIDE PRIVY AT 12 FT. BELOW CORE MIDPLANE	-	-	3.47 (6)	-	2.47 (6) ^(e)	1.56 (6)
	5.00 (6)	6.30 (6) ^(e)	-	-	-	-

(a) Preliminary data from NRX-A2, EP-2

(b) No data is yet available

(c) KIWI B4A EP5 Point 17 (LA 2885)

(d) KIWI B1A EP5 Point 31 (LA 2858)

(e) KIWI B1A EP5 Point 20 (LA 2858)

TABLE VIII

NRX A PRIVY ROOF MOUNTED SHIELD

FIG 6

**MOUNTED SHIELD SHADOW PROJECTION
(TEST CELL "A" WALL)**

FIG 7

VERTICAL SHIELD CROSS SECTION

FIGURE 8

CONCLUSIONS AND RECOMMENDATIONS

A study of the addition of a partial right cylindrical radiation shield on top of the privy roof has indicated the modifications required, as well as a number of pertinent conclusions:

1. The capability of actuator seals and hydraulic fluid to withstand the accumulated radiation dose associated with more than 30 minutes of NRX full power operations is considered to be a problem.
2. The total dose below the privy roof will be reduced by a factor of approximately 10 - 15 and on the front of the car by a factor of 15 - 20 with the proposed 135° sector shield.
3. The direct gamma and fast neutron dose at the core midplane seen by the front face of the test cell wall will be reduced by a factor of approximately 30 and 25, respectively with the proposed 135° sector shield.
4. The shadow which the proposed 135° sector shield casts upon the test cell wall will protect the entire front face of the test cell wall from nuclear heating damage⁽¹⁾ and radiation activation.
5. A standard NRX test car can be fitted with the shield without excessive modifications to the test car.

As a result of this investigation, the following is recommended:

1. The NRX-A3 test assembly be assigned to accept the privy roof mounted shield for testing in preparation for tests longer than 30 minutes.
2. The shield design be firm by December 21 to facilitate material acquisition by mid January 1965.

⁽¹⁾ Analysis of gamma heating at test cell wall is contained in Appendix II.

3. Fabrication begin by mid January 1965.
4. More precise analyses and the affects of the shield relative to the test assembly should be continued and finalized by February 1965.

COST AND SCHEDULE ANALYSIS

A detail study of the fabrication costs of the proposed shield (135° right cylindrical section) has resulted in the following estimates:

Shield 135° Sector

Raw Materials	9,822	
Fabrication Costs	27,506	
Sub-Total		37,328

Test Car Hardware Changes to Incorporate Shield (Fabrication Only)

Water System Plumbing	2,480	
Emergency Purge Plumbing	3,670	
Vent and Collector System	830	
Sub-Total		<u>6,980</u>
Total Cost of Adding Shield		\$ 44,308

The fabrication schedule for the shield has been estimated to be 100 to 115 days. This is based on a known availability of material, machine time at ACF, and the design drawings and layouts completed as of December 17, 1964. Assuming a go-ahead date of December 21, 1964, this shield will be available at NRDS between April 1 thru April 15, 1965. Fabrication will begin, based on a December 21, 1964 go-ahead date, by mid January 1965.

It can be placed on the test car within five to seven days after receipt at NRDS at either the R-MAD building or at Test Cell "A".

Hardware will be provided, for the systems affected by the inclusion of the shield, so that reactor tests could be performed with or without the shield.

APPENDIX I

NEUTRONS AND GAMMA RAYS SCATTERED FROM THE TEST CELL WALL AND PAD:

Calculations of radiation levels resulting from wall and pad scattering were made using a multiple scatter albedo model suggested by A. Foderaro.⁽¹⁾

The neutron albedo formula used is:

$$D = D_o A \beta \cos 2/3 \theta_o \cos \theta / r^2$$

where: D = Scattered neutron flux at detector

D_o = Neutron flux incident on a scattering area

A = Scattering area

β = Neutron dose albedo for normal incidence and reflection
on concrete (~ 0.111 for neutron energies greater than 1 MEV)

θ_o = Angle between the incident ray and the normal to the scattering area

θ = Angle between the reflected ray and the normal to the scattering area

r = Distance between the center of the scattering area and the detector point

In the case of gamma rays, the albedo equation used was:

$$D = D_o A \beta \cos \theta / r^2$$

where β is the energy albedo for gamma rays at normal incidence and reflection on concrete.

Following the suggestion of A. Foderaro, a scale model of the test cell wall and pad including privy roof shield and reactor core center was constructed. The use of the scale model in the hand calculations facilitated measurement of the angles θ_0 and θ_r and the distance, r . In addition the model permitted immediate determination of whether the detector point was shielded. The wall and pad were divided into 43 and 38 scattering areas respectively for purposes of computing the scattered radiation levels under the privy roof shield and on the test car.

GAMMA FROM NEUTRON CAPTURE IN THE WALL

Hand calculation of the gamma dose rate at the detector resulting from neutron capture in the test cell wall was based on the following assumptions:

1. Removal of a fast neutron results in the immediate generation and capture of a thermal neutron (N-2-3062, Estimation of Total Dose Rate Below Privy Roof Shield, R. E. Malenfant, February 8, 1961).
2. Thermal neutrons incident on the wall are captured at the concrete surface.
3. Each capture results in the generation of a 6 MEV photon emitted isotropically.
4. The effect of distance attenuation within the wall may be neglected in the case of the incident beam.
5. The photons are assumed to be generated a distance of $1/\mu$ in the wall for purposes of computing the inverse R^2 effect of distance between source and detector point.

The derivation of the equations used in this calculational model is shown

below:

The incident fast neutron beam is attenuated in the test cell wall as a function of the slant penetration distance ρ_1 , i. e.:

$$S(\rho_1) = S_0 e^{-\Sigma_r \rho_1}$$

where

$$S(\rho_1) = \text{fast neutron flux at } \rho_1$$

S_o = fast neutron flux at the surface

Σ_r = Removal cross section

The number of neutrons removed in the element of path length $d\rho_1$ is:

$$S_o \Sigma_r e^{-\Sigma_r \rho_1} d\rho_1$$

From assumption (1) and (3), the isotropic emission rate at ρ_1 in the internal $d\rho_1$ is:

$$6S_o \Sigma_r e^{-\Sigma_r \rho_1} d\rho_1$$

The photon beam directed toward the receiver point is attenuated as a function of the slant penetration of the emergent beam. The photon flux, I_o , at the wall surface is therefore:

$$dI_o = 6S_o \Sigma_r e^{-\Sigma_r \rho_1} \frac{e^{-\mu \rho_2}}{4\pi \rho_2^2} d\rho_1$$

The above expression may be written in terms of a normal penetration, r , the incident angle θ_o , and the emergent angle θ because:

$$\rho_1 = r \sec \theta_o$$

$$d\rho_1 = \sec \theta dr$$

hence:

$$dI_o = \frac{6S_o \Sigma_r r^{-r(\Sigma_r \sec \theta_o + \mu \sec \theta)} \sec \theta_o dr}{4\pi \rho_2^2}$$

In order to simplify the integration, it is assumed for distance attenuation purposes that all of the gammas are generated one relaxation length from the surface along the slant path ρ_2 ; then the photon beam directed toward the receiver point due photons generated through the wall ($r = 0$ to $r = t$) is:

$$I_o = \int_0^t \frac{6S_o \sum_r e^{-r} (\sum_r r \sec \theta_o + \mu \sec \theta)}{4\pi \left(\frac{1}{\mu}\right)^2} \sec \theta_o dr$$

$$I_o = \frac{6S_o \sum_r \sec \theta_o}{4\pi \left(\frac{1}{\mu}\right)^2 (\sum_r \sec \theta_o + \mu \sec \theta)} \left[1 - e^{-t (\sum_r \sec \theta_o + \mu \sec \theta)} \right]$$

The total beam directed toward the receiver point is equal to the area of a surface of assumed uniform incident flux times the above expression. The total arriving at the receiver point, a distance R away from the source area is:

$$I_o = \frac{6S_o \sum_r \sec \theta_o (A \cos \theta_o)}{4 \left(R + \frac{1}{\mu}\right)^2 (\sum_r \sec \theta_o + \mu \sec \theta)} \left[1 - e^{-t (\sum_r \sec \theta_o + \mu \sec \theta)} \right]$$

The total gamma intensity at the receiver point including the photons resulting from captures of thermal neutrons from the reactor at the surface of the test cell wall is therefore:

$$I(\text{Total}) = \frac{I_o + 6 \phi_{th} (A \cos \theta_o)}{4\pi R^2}$$

The test cell wall was divided into 43 areas for purposes of computing the gamma dose rate under the privy roof and at test car locations. Thermal neutron fluxes for $E < 1.86 \text{ EV}$ and fast neutron fluxes for $1.86 \text{ EV} < E < 10 \text{ MEV}$ were obtained from WANL-TNR-128.⁽²⁾

AIR SCATTERED NEUTRONS

An "upper limit" estimate of the neutron flux under the privy roof resulting from air scattered neutrons was obtained from data in reference (3). The referenced data are presented as a curve of air scattered neutron dose rates as a function of the angle of emission of a 1.1 MEV point monodirectional source for a source-detector separation distance of ten feet. The data, presented in Rem hr^{-1} per source neutron- sec^{-1} were converted to Rads (tissue) by dividing by an RBE of 8⁽⁴⁾ and put on a flux greater than 1 MEV basis by multiplying by a flux-to-dose factor of 4.85×10^4 obtained from WANL-TNR-128.

Hence:

$$F(\theta) \frac{\text{neutrons } (E > 1 \text{ MEV})/\text{cm}^2 \text{ sec}}{\text{source neutron/sec}} = f(\theta) \frac{\text{rem/hr}}{\text{source neutron/sec}} \times \frac{4.85 \times 10^4}{8}$$

These data were subsequently applied to the flux emitted in the unit solid angle $d\Omega$ centered about the polar angle at ten feet from the reactor in WANL-TNR-128.

$$S(\theta) d\Omega = \frac{[S(\theta)]_{10 \text{ ft.}} \times 4\pi (10 \text{ ft.} \times 30.5 \text{ cm/ft.})^2}{4\pi \text{ solid angle}} \frac{\text{source neutron/sec}}{\text{unit solid angle}}$$

Unit solid angle is $d\Omega = \sin \theta d\theta d\phi$ where θ and ϕ are polar and azimuthal angles respectively. The air scatter neutron flux ten feet from the anisotropic point source is therefore:

$$N = \int_{\theta} \int_{\phi} F(\theta) S(\theta) \sin \theta d\theta d\phi$$

Because of the aximuthal symmetry of the functions, ϕ is integrated from 0 to 2π , the because the privy roof subtends an angle of about 45 degrees with respect to core center, θ is integrated from $\pi/4$ to π . Put in incremental form for purposes of numerical integration, N becomes:

$$N = 2\pi \sum_{45^{\circ}}^{180^{\circ}} F(\theta) S(\theta) \sin \theta \Delta \theta$$

Trapezoidal integration was performed to obtain a value of 1.6×10^{-10} $\frac{\text{neutrons/cm}^2 \text{ sec}}{\text{fission sec}}$ for the air scattered neutron flux with energies greater than 1 MEV.

The value for the air scattered neutron flux is a conservative upper limit because:

1. The presence of the test cell wall and pad which limits the volume of air in which the scattering occurs was not taken into account.
2. Some of the scattered neutrons resulting from source neutrons emitted at polar angles between 45° and 180° must pass through the privy roof to arrive at the detector point. This was not accounted for in the calculation.

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3. Reactor Handbook, Vol. III, Part B, Shielding - E. P. Blizard, Editor, 1962
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APPENDIX II

GAMMA HEATING OF TEST CELL "A" WALL

The east wall of the FCR (Flow Control Room) at Test Cell "A" is reinforced concrete 5.5 ft. thick. The east wall above the FCR is 20 in. thick. During 1963, a backup thickness of concrete was poured behind the 20 in. thickness to make the total wall cross section the same as the lower part (5.5 ft.). During reactor operation, the wall receives energy deposition from both gamma heating and flame radiation. The maximum gamma heating takes place at the projected intersection of the core midplane with FCR wall. This calculated energy deposition rate at the surface of the wall is shown in Figure II-1. It is attenuated to approximately 1/10 of its original value in 10 inches. The energy deposition rate at the surface is 35,000 BTU/hr-ft³. A calculation of the energy deposition from flame radiation indicates an energy deposition rate of 19,000 BTU/hr-ft³ at the surface. The flame radiation energy is assumed to be entirely deposited at the surface. Using the heating rates in Figure II-1, a temperature distribution in the concrete wall was calculated using the numerical solution outlined in WANL-TME-347.

The results of these calculations are plotted in Figure II-2 for full power operating times of 5, 10, 15 and 20 minutes. Also plotted are the ΔT experimental data from NRX-A2. Since convective heat transfer from the surface is included in the calculations, the maximum temperature is transposed in from the surface. However, the transient temperature calculation method does not include the flame radiation. Since this heat is all deposited on the surface the poor conduction of the concrete combined with the shortness of the test should leave the integrated energy near the surface. The dotted lines directed upward near the surface for

each temperature curve is an attempt to indicate how the actual distribution should appear when the flame radiation is included. The gamma dose rate falls off rapidly along the wall away from the point of intersection of the core midplane.

Curves six (6) and seven (7) of Figure II-2 are NRX-A2 data. Thermocouples were placed into the wall at the core midplane. The curves are both displaced to bring the initial temperature distribution in line with the initial distribution used for the calculations. It is believed that a calibration error existed since the initial distribution in the data was around 180°F. The assumption was made that the ΔT between initial and final values is approximately correct.

The calculated curves 1, 2, 3 and 4 assume an initial temperature distribution of 100°F. The temperature distribution (1) is equivalent to (7) for equivalent time at full power. In comparing the revised to (7) for equivalent time at full power. In comparing the revised experimental data with the calculations, it is immediately apparent that:

1. The gradient is less into the wall (experimental). This is possibly due to the increased conduction in the reinforcing rods. The steel was not considered in the calculations. Better conduction may be due to the design of the thermocouple block with lead wires.
2. The total energy deposited in the wall is greater (experimental). This is possibly due to the steel neglected in calculations. The hump in the calculated temperature curves is due to the convective heat transfer from the surface which effectively pushes the maximum back from the surface.

The calculations were performed in a similar manner to TMI-347 "Numerical Solution of Transient Temperature Distribution in Concrete Wall of Test Cell 'A ' Due to Gamma Heating." An increased energy deposition rate at the surface of the wall of .35 watts/cm³ was used.

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