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E-MAD FACILITY
PHASE I
NUCLEAR SHIELDING REPORT

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CONTENTS

	<u>Page</u>
INTRODUCTION	1
DESIGN CRITERIA	2
GAMMA SOURCES	4
Core Source	4
Engine Source	4
Distance Attenuation of the Unshielded Engine Source	4
Distance Attenuation of the Shielded Engine Source	8
Decay After Shutdown of Core Source	10
Integrated Dose Calculation	10
Activation of Engine Parts	13
Decay of Dose for Engine Parts	15
Plating and Fission Products on the Nozzle	17
CALCULATION OF ATTENUATION THROUGH SHIELDING MATERIALS	18
DOSE IN THE CONTROL ROOM AND SHELTER AREAS FROM THE ENGINE BEFORE IT ENTERS THE MAIN DISASSEMBLY BAY	36
Function of the Shelter Areas	36
Dose in the Master Control Room and Shelter Areas	36
DOSE RATES IN THE OPERATING GALLERIES	40
Main Bay	40
Direct Dose from Core	40
Direct Dose from Activated Engine Parts	40
Physical Location of the Core While Part of the Engine	43
Scattered Dose Rate	44
Calculation of Roof Thickness	47
Safety Factors	50
Core Disassembly Cells	52
Engine Hold Tunnel	53
Counting Room	54

	<u>Page</u>
LOCAL SHIELDING	55
Doors	55
Personnel Doors (122/3, 122/4, 306/1, and 306/2)	55
Main Disassembly Bay Door (122/1)	55
Door to Engine Hold and Transfer Tunnel (122/2)	56
Exit Door from Hold and Transfer Tunnel (128/1)	57
Doors to the Core and Engine Disassembly and Examination Cells (127/1 and 130/1)	57
East and West Doors to the Crane Maintenance Balcony (306/3 and 306/4)	58
Windows	60
Steel Collars for Shielding Windows	65
Oil Lifetime in the Windows	67
Ducts and Penetrations	71
Instrumentation Penetrations	74
Mechanical Penetrations	75
Air Ducts	76
Main Bay Fuel Module Storage Pit	78
RADIATION DAMAGE	79
NUCLEAR HEAT LOAD TO FACILITY	81
STACK HEIGHT ANALYSIS	82
RADIATION MONITORING	85
TESTING AND CHECKOUT OF SHIELDING WALLS	89

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INTRODUCTION

The E-MAD engine maintenance assembly and disassembly facility, to be located at Jackass Flats, Nevada, will provide a shielded building in which nuclear rocket engines may be disassembled, examined, maintained and reassembled after having been tested at full power. The need for this facility as part of the Nuclear Rocket Development Station is based upon a program whose goal is the flight of a nuclear rocket by 1966 or 1967. The E-MAD building and supporting facilities have been engineered to accommodate the NERVA and Phoebus engines and reactors, after full power firing, at the earliest feasible time that the radioactive engine may be transported from the test stand into the E-MAD building.

Basic operational requirements have been established by the industrial team developing the engine: Aerojet General as NASA prime contractor, with Westinghouse Astro-Nuclear Lab and AMF Atomics as subcontractors. Technical review of these operational requirements has been provided by the Space Nuclear Propulsion Office - Cleveland (SNPO-C) of NASA/AEC. In addition, specific technical information on the KIWI Program has been provided by the Rover Project personnel at Los Alamos and the Nevada Test Site.

The operational requirements include the physical size of the building, the accommodations required for separate shielded disassembly areas, the viewing and handling requirements, and the general flow of radioactive material through the facility. The shielding design is presented as the best possible one, commensurate with minimum cost, which meets these requirements, and will protect the operating personnel from the radiation associated with an exposed nuclear engine.

DESIGN CRITERIA

While the E-MAD facility has been designed to handle the NERVA engine, the shielding, in order to provide flexibility for future generation engines, has been designed for the Phoebus engine 24 hr after shutdown. Because of operational limitations, such as forced cooling requirements for the decay heat load, no engine can be transported to the E-MAD building prior to 24 hr after reactor shutdown.

The facility is designed to insure that the total dose received by the individual closest to the source will be within Nevada Test Site Rad Safe conditions. The shielding design of the facility is based on maintaining a dose rate which does not exceed AEC regulations.

The permissible exposure as set forth in the rules and regulations of the Atomic Energy Commission, Title 10, Part 20, establishes a gamma dose limit of $1-1/4$ rems/calendar quarter for the whole body. This applies to the head and trunk, the active blood forming organs, the lens of the eyes and the gonads. For the hands and forearms, feet and ankles the dose limit is $18-3/4$ rems/calendar quarter. The dose limit to the skin of the whole body is $7-1/2$ rems/calendar quarter. The regulation also provides that a licensee may permit an individual in a restricted area to receive a dose to the whole body greater than $1-1/4$ rems/calendar quarter provided: "1) during any calendar quarter the dose to the whole body from radioactive material and other sources of radiation in the licensee's possession shall not exceed 3 rems; and 2) the dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N-18) rems where "N" equals the individual's age in years at his last birthday."

If a uniform dose were to be received each week by an individual over an entire year, the limiting dose rate would be 100 mr/wk. The shielding design is based upon this latter criterion, and further assumes one engine test per week. It is assumed that the engine arrives at the E-MAD building after its third successive full power run at its earliest possible time of arrival of 24 hr after shutdown. It is further assumed that a single individual is always in a position which exposes him to the highest dose rate from the engine, at the closest distance of approach defined in

the report, throughout 40 hr divided in five 8 hr shifts, spaced at 24 hr intervals.

The areas of the facility which meet or exceed these design requirements include:

1. all operating galleries
2. the area outside the E-MAD building at ground level
3. the cold bay
4. all uncontrolled areas

In addition to the areas listed above, a number of limited access areas are designated. In these areas personnel do not work on a 40 hr/wk basis, and the areas need be entered only for maintenance of handling equipment, for placement or removal of equipment, and for decontamination. These operations normally require short access times. The limited access areas include:

1. the main disassembly bay while an engine is in the hold tunnel or a core is in the balcony.
2. the balcony while the core or "fresh engine" is in the main bay
3. the engine hold tunnel while the core is either in the main bay or in either of the adjacent disassembly cells.

These areas are all designed for access 24 hr after engine shutdown. They may be entered only after any radiation sources in the immediate area have been removed and the shielding doors to adjacent hot areas closed. Lower dose rates and longer access in these areas can be achieved by moving the source to a more sheltered position with respect to the area to which access is required.

The shelter area, including areas 109, 110 and 111 as shown on Vitro Drawing 1425-R-1, is designed to protect personnel as the hot engine is transported from the test stand to the main disassembly area. The shielding for this area is designed to limit the maximum dose rate in the shelter, during the approach of an engine, to 25 mr/hr at the moment when the dose rate in the shelter is greatest before the engine enters the main bay. This produces an integrated dose of 2 mr during the approach of an engine. Other shelter areas are the basement underpass and the master control room. The dose in these areas is also <2 mr.

GAMMA SOURCES

CORE SOURCE

The gamma source spectrum from a bare Phoebus core, 24 hr after the third shutdown from a full power run is given in Table 1. The gamma flux in $\text{mev}/(\text{sq cm})(\text{sec})$ and the unshielded dose rates in r/hr , 10 ft from the bare core are listed.

ENGINE SOURCE

The engine consists of the bare core surrounded by a pressure vessel and thermal shield, which serve to attenuate the radiation from the bare core, by a factor of 3.8, if no other shielding is present. The effect of this shielding, when a 5 ft concrete wall is interposed between the source and the detector, is an attenuation factor of 2.9. The factor is smaller when there is a biological shield present, because the dose rate that gets through this shield is primarily due to the higher energy gammas, which are attenuated to a lesser degree by the pressure vessel and thermal shield.

DISTANCE ATTENUATION OF THE UNSHIELDED ENGINE SOURCE

The radiation source level of the Phoebus engine 24 hr after shutdown as a function of distance from the engine has been calculated for 10 to 3,600 ft. The results are shown on Fig. 1. The curve indicates that a distance of 3,500 ft is required to reduce the dose to $2\frac{1}{2}$ mr/hr . The effect of air attenuation is included, since it plays a significant role in attenuation at the distances involved. Curves for the attenuation of the individual energy groups, representative of the engine source are shown in Fig. 2. The dose rate in and around the unshielded parts of the E-MAD building when the engine is $\frac{1}{2}$ mile away will be 20 mr/hr .

TABLE 1

GAMMA SPECTRUM AND DOSE RATE FROM AN UNSHIELDED PHOEBUS CORE
24 HOUR AFTER SHUTDOWN
(CORE SELF SHIELDING IS INCLUDED)

Average Gamma Energy (mev)	Energy Range (mev)	Gamma Flux 10 ft from core (mev/(sq cm)(sec))	Conversion Factor, G r/hr <hr/> mev(sq cm)(sec)	Dose Rate 10 ft from core (r/hr) <hr/>
0.3	0.0 - 0.4	5.64×10^9	1.8×10^{-6}	10,150
0.7	0.4 - 0.9	3.38×10^{10}	1.84×10^{-6}	62,190
1.0	0.9 - 1.35	1.28×10^{10}	1.74×10^{-6}	22,272
1.5	1.35 - 1.8	7.78×10^9	1.60×10^{-6}	12,448
2.0	1.8 - 2.2	1.09×10^{10}	1.48×10^{-6}	16,132
2.5	2.2 - 2.6	9.64×10^8	1.35×10^{-6}	1,301
2.8	2.6 - 3.0	1.96×10^7	1.30×10^{-6}	25.5
3.5	3.0 - 4.0	2.29×10^7	1.23×10^{-6}	28.2
				<hr/> 124,547

Source: WANL

FIG. 1 TOTAL DOSE RATE VS DISTANCE
(24 Hr After Shutdown; Including Air Attenuation)

FIG. 2 ATTENUATION FACTOR VS DISTANCE IN AIR FOR UNSHIELDED ENGINE

Therefore, all personnel must have found shelter before the engine gets to within 1/2 mile of the facility, and preferably should reach shelter before the engine is 2/3 of a mile from the E-MAD building.

DISTANCE ATTENUATION OF THE SHIELDED ENGINE SOURCE

The effect of distance attenuation is somewhat different when the engine is behind a shielded wall. The dose rate from the engine (with the dose point at the point of highest dose rate, at the centerline of the engine, normally through the shield wall) follow the basic relationship:

$$D = \frac{GBSv R_o^2}{2(a+z)} F(\theta, b_2)$$

For a given shield thickness, the distance attenuation varies as:
 $F(\theta, b_2) / a$

where:

$$F(\theta, b_2) = \int_0^{\theta} e^{-b \sec \theta} d\theta$$

a = distance from surface of core to dose point.

The dose rate at any distance "a," in terms of the dose rate at 10 ft from the core surface, as listed in Table 1, is expressed as follows:

$$\frac{D(a)}{D(10)} = \frac{F(\theta_a, b) / a}{F(\theta_{10}, b) / 10 \text{ ft}}$$

where $D(a) / D(10)$ is the dose rate at distance "a," normalized to the dose rate 10 ft from the core. A plot of the normalized dose rate vs distance is shown in Fig. 3.

FIG. 3 DISTANCE ATTENUATION FACTOR NORMALIZED TO 10 FT

DECAY AFTER SHUTDOWN OF CORE SOURCE

The decay of the gamma ray activity from the core, after a full power run is shown in Fig. 4. This curve is based on data presented in ANP Document No. NARF-58-37T, "Calculated Gamma Ray Spectra From U^{235} Fission Products." This curve does not represent the true operating time of the reactor. It is used only to establish the decay after shutdown of the significant energy groups.

INTEGRATED DOSE CALCULATION

In order to evaluate the integrated dose to meet the criterion that a man receive no more than 100 mr/wk in a series of five 8 hr shifts spaced one day apart, the curves of gamma energy vs time are integrated to determine the effect of the source strength decay. This is done as follows. The gamma energy vs time is plotted for 8 hr intervals starting at 24 hr, 48 hr, 72 hr, etc. The area under these segments is then graphically computed for the significant energy groups. The gamma energies of interest are grouped separately, as follows:

Energy Group* (mev)	Average Gamma Energy** (mev)	Relative Dose Through 5 ft Conc. (mr/hr)
0 - 1	0.3, 0.7, 1.0	0.3
1 - 2	1.5, 2.0	40
2 - 3	2.5, 2.8	10
3 - 4	3.5	1.2

It may be seen that the dose through a 5 ft concrete wall is primarily due to the 1-2 mev and 2-3 mev groups. In calculating the decay of the total dose with time, and the integrated dose, these two groups have been considered as shown in Fig. 5, and the relative contribution from each group as a function of time has been weighed in terms of the relative dose through 5 ft of concrete given above.

*From data presented in ANP Document No. NARF-58-37T

**Data supplied by Westinghouse Astro-Nuclear Laboratory

SOURCE: ANP DOCUMENT NUMBER: NARF-58-377

FZK-9-132

FIG. 4 GAMMA ENERGY VS TIME AFTER SHUTDOWN

FIG. 5 INTEGRATED GAMMA ENERGY VS TIME AFTER SHUTDOWN
(For 8 Hr Shift Operation)

The decay factor is then computed as follows. The integral of the shaded areas under the curves in Fig. 5 is:

$$I = \left[\text{mev}/(\text{sec})(\text{watt}) \right] \times 40 \times 3600 \text{ sec/hr}$$

Therefore the average dose rate for a 40 hr period is:

$$A(40) = I/1.44 \times 10^5.$$

This must be normalized to the instantaneous dose rate 24 hr after shutdown, $E(24)$. The ratio $A(40)/E(24)$, weighed by the ratio of relative doses for each decay group, = 0.276. This is the decay factor or the reduction in the initial dose/hr x 40 hr which is due to the decay of the source.

To obtain the weekly dose for a set of 8 hr shifts, spaced at one day intervals, when the dose rate at the beginning of the first shift is known, the initial dose rate at the beginning of the first shift, corresponding to the dose 24 hr after reactor shutdown, is multiplied by 0.276 (the decay factor) x 40 hr.

Thus: weekly dose = 11 x dose rate (mr/hr) 24 hr after shutdown

Therefore if the entire dose rate being considered derives from the core source, and the same individual is exposed to the maximum dose rate from this source 8 hr/day for 5 days a week, for 50 weeks/year, (with a fresh source replacing the old one each week), the maximum initial dose rate that this individual may receive at the beginning of each weekly cycle is 9 mr/hr, if both he and the engine are to remain in the same relative positions for a standard 40 hr week, with a new engine each week.

ACTIVATION OF ENGINE PARTS

Data on anticipated dosage due to activation of engine parts is presented in Table 2. The source of this data is the Nuclear Department of Aerojet General, the engine manufacturer. The table lists dosage, at 10 ft from the part in question, after 1 day and after 2-1/2 days decay fol-

TABLE 2
ACTIVATION OF ENGINE PARTS

	Part	Material	Weight (lb)	Dose Rates		Confidence Factor
				1 day (mr/hr)	2-1/2 day (mr/hr)	
	Gimbal Actuators	347 ss	100	51.6	12.8	10
	Control Actuators	347 ss	20	68.4	17.2	10
	Gimbal	17-7 PH ss	40	11.6	3.2	10
	Pressure Vessel					
	Head	Al 7079	212	2,680.0	543.0	10
	Pressure Vessel					
	Shell	Al 7079	1,248	157,500.0	32,000.0	3
	Nozzle Tubes	347 ss	825	28,200.0	7,070.0	3
	Nozzle Shell	Al 7079	275	13,880.0	2,810.0	3
	Turbopump					
	Housing	A 356	150	127.2	23.2	10
	Turbopump					
	Rotating Assy.	Steel A 286	100	86.4	33.6	10
	Upper Thrust					
	Structure	347 ss	1,510	516.0	129.0	10
	Lower Thrust					
	Structure	347 ss	320	329.0	82.2	10
	Pressure Vessel					
	Bolts	Steel A 286	75	8,080.0	3,140.0	10
	Reflector 1	*	-	88.0	15.0	1
	Reflector 2	*	-	9,500.0	1,700.0	1
	Thermal Shield	*	-	48,000.0	0.25	1
	Support Plate	Al	-	220,000.0	45,000.0	1

*Material is classified. To be consistent with other data in the table only the 2 mev (and above) average energies are included herein. Lower energies contribute negligibly to the dose outside a 5 ft concrete wall.

lowing a third full power run in one month. Since these dosages are anticipated values and have a degree of uncertainty, corresponding confidence factors are also presented. To provide an adequate factor of safety the product of the anticipated dosages and their confidence factors have been taken as the source levels for the design of the walls. It has been estimated by Aerojet that the self shielding factor for the engine parts while they are part of the engine should be taken as a factor of 0.5. For example, only 1/2 the pressure vessel shell faces the shielding wall and dose point. The other half is shielded by the core. The total dose rate from the significant energy group of 2.75 mev gamma from $\text{Al}(n, \alpha) \text{Na}^{24}$, with engine self shielding considered is 2.3×10^5 mr/hr.

The gamma spectrum to be used for designing the shielding was specified by Aerojet as follows:

"In general, for 1 day and 2-1/2 days in aluminum components, the shield can be sized as if 60% of the dose is caused by 2.75 mev gammas and the remaining 40% comes from 2 mev gammas." All steel was specified by Aerojet as having an effective gamma energy of 2 mev.

DECAY OF DOSE FOR ENGINE PARTS

When the sources listed in Table 2 are attenuated by a 5 ft shield wall, the principal source which gives rise to the dose from activated engine parts is 2.75 mev gamma from the fast neutron flux (n, alpha) activation of aluminum to Na^{24} , which decays with a 15 hr half life. An approach similar to the one applied to the core decay is used to calculate the decay factor and integrated dose due to Na^{24} for five 8 hr shifts commencing 24 hr after reactor shutdown. The curve of the decay of Na^{24} is shown in Fig. 6.

The integral of the shaded areas under the curve is 3.28. Therefore, this factor multiplied by the initial dose from the engine parts of a fired engine equals the dose per 40 hr week. The dose 24 hr after shutdown $= 2 \exp^{-(24/15)} = 0.33 \times$ initial dose. Therefore the total weekly dose, related to the dose rate 24 hr after shutdown is $3.28/0.33$ or 9.95 times the dose rate 24 hr after shutdown.

FIG. 6 DECAY OF 2.75 MEV GAMMAS FROM Na^{24}
(Integrated For 8 Hr Shift Operation)

PLATING AND FISSION PRODUCTS ON THE NOZZLE

During the operation of the Phoebus engine, it is anticipated that a maximum of 7% of the fission products can escape from the core. Of these, it is further assumed that 5% may plate out on the nozzle. These figures are based on recommendations by Los Angeles Scientific Laboratory (LASL), which established the maximum anticipated activity due to fission product plating.

The activity levels for the core are based on a full core inventory of fission products. No credit has been taken for the loss of fission products from the core. Therefore, in the full engine configuration, the only additional contribution to the dose from the fission products which are plated out on the nozzle is due to the fact that they are not shielded by either the core, the thermal shield, or the pressure vessel. However, in the case where the dose rate from the core at a distance of 10 ft is calculated at the center plane of a core, the nozzle throat, where most of the plating takes place, is several feet below the core center plane. The gammas from this source must penetrate a greater slant thickness of shielding to reach the dose point. Without specifying classified dimensions, it may be said that the additional attenuation due to this slant penetration fully compensates for the loss of self-shielding which the plated out fission products have attained.

In the case of the dose rate to the upper gallery, there is an even greater effect of slant penetration to the dose point than in the case of the dose at core center plane. Therefore, no additional contribution to the dose from the full engine is produced by the plated fission products on the nozzle. In the case of the dose rate in the lower gallery, where the core is above the nozzle, the effect of this self shielding loss is considered. In the lower gallery this is more than compensated for by the attenuation of the scattered dose from the roof by the 6 in concrete floor of the upper gallery.

CALCULATION OF ATTENUATION THROUGH SHIELDING MATERIALS

The basic equation for calculating the dose at the midplane of a cylindrical source, as given in Rockwell* is of the form:

$$D = \frac{B \text{ Sv } C \text{ Ro}^2}{2 (a + z)} F (\theta, b_2)$$

Where

- D = dose rate, r/hr
- Sv = volumetric source strength, mev/(cu cm)(sec)
- C = conversion factor, r/hr/mev/(cu cm)(sec)
- R = radius of core
- a = distance between core surface and dose point
- z = self absorption distance in source
- B = symbolic buildup factor = $A_1 e^{-a_1 \mu t} + A_2 e^{-a_2 \mu t}$
- F = $(\theta, b_2) = \int_0^\theta e^{-b \sec \theta} d\theta$
- b = linear absorption coefficient of shield x thickness of shield = μt

When the dose point being considered is not at the midplane of the source, and where slant penetration through a slab shield to the dose point is considered, as for example when the core is below the floor level of the upper gallery and the dose in this gallery is required, the following basic equation is used:

*TID 7004, U.S. Atomic Energy Commission, Washington, D.C.,
"Reactor Shielding Design Manual," Edited by T. Rockwell, 1956.

$$\phi = \frac{BS_V R_O^2}{4(a+z)} \left[\int_0^{\theta_1} e^{-b \sec \theta} d\theta + \int_0^{\theta_2} e^{-b \sec \theta} d\theta \right]$$

or

$$\phi = \frac{BS_V R_O^2}{4(a+z)} \left[F(\theta_1, b_2) - F(\theta_2, b_2) \right]$$

In the above equations a symbolic buildup factor B is used. This however, does not account for the fact that the buildup should be integrated as a function of $b \sec \theta$. In order to include the buildup factor in the geometric integral, the following approach is taken.

With no external shield, the flux at the dose point due to a differential core height dL would be:

$$d\phi = \frac{\pi R_O^2 S_V dL}{4\pi (a+z)^2 \sec^2 \theta} \quad \text{mev}/(\text{sq cm})(\text{sec})$$

This radiation passes through two shields: a) a thickness $z \sec \theta$ cm of source material, having a linear absorption coefficient μ_s ; and b) a thickness $t \sec \theta$ cm of shield proper, having a linear absorption coefficient μ , or μ_1 for an energy E_1 .

Without buildup, the combined attenuation of the two shields is:

$$\phi / \phi_0 = e^{-\mu_s z \sec \theta} e^{-\mu_1 t \sec \theta}$$

The flux at P, due to dL , without buildup, is:

$$d\phi = \frac{R_O^2 S_V e^{-(\mu_s z + \mu_1 t) \sec \theta}}{4(a+z)^2 \sec^2 \theta} dL \quad \text{mev}/(\text{sq cm})(\text{sec})$$

To permit integration with respect to θ , dL must be expressed in terms of $d\theta$. The relation between $d\theta$ and dL is illustrated in the figure below:

$a + z$ = the distance from source to dose point plus the self absorption distance of source.

Thus: $dL = (a + z) \sec^2 \theta d\theta$

The flux at P due to dL , without buildup, is:

$$d\phi_{N.B.} = \frac{R_0^2 S_v e^{-(\mu_s z + \mu_1 t)} \sec \theta}{4 (a + z)} d\theta$$

The buildup factor is expressed as the sum of two exponential expressions, as follows:

$$B(E_0, \mu x) = A_1 e^{-a_1 \mu x} = A_2 e^{-a_2 \mu x}$$

where "x" represents the actual uncollided path length through the shield, for a transverse shield thickness of:

$$x = t \sec \theta$$

A_1 , A_2 , a_1 , and a_2 are constants depending on the shield material and the initial gamma energy. They can be evaluated by means of curves given on pp. 416 and 423 of the "Reactor Shielding Design Manual," by Rockwell.

A list of absorption coefficients and buildup factors for various shielding materials is presented in Table 3.

Thus, the buildup factor for the radiation from dL is:

$$B = A_1 e^{-a_1 \mu_1 t \sec \theta} + A_2 e^{-a_2 \mu_1 t \sec \theta}$$

Therefore, the flux at P due to dL , including the buildup factor through the shield, is:

$$d\phi = \left[\frac{R_0^2 S_V e^{-(\mu_s z + \mu_1 t) \sec \theta}}{4 (a + z)} d\theta \right] \times$$

$$\left[A_1 e^{-a_1 \mu_1 t \sec \theta} + A_2 e^{-a_2 \mu_1 t \sec \theta} \right]$$

and

$$d\phi = \frac{R_0^2 S_V}{4 (a + z)} \left[A_1 e^{-(\mu_s z + (1 + a_1) \mu_1 t) \sec \theta} + \right.$$

$$\left. A_2 e^{-(\mu_s z + (1 + a_2) \mu_1 t) \sec \theta} \right] d\theta$$

Assuming:

$$b_4 = \mu_s z + (1 + a_1) \mu_1 t$$

and

$$b_5 = \mu_s z + (1 + a_2) \mu_1 t$$

Then:

$$d\phi = \frac{R_0^2 S_V}{4 (a + z)} \left[A_1 e^{-b_4 \sec \theta} + A_2 e^{-b_5 \sec \theta} \right] d\theta$$

TABLE 3

PROPERTIES OF COMMON SHIELDING MATERIALS

<u>Coefficient or Factor</u>	<u>Energy Group</u>	<u>Average Energy</u>	<u>Ordinary Concrete</u>	<u>Barytes Concrete</u>	<u>Steel</u>	<u>Lead</u>
ABSORPTION COEFFICIENTS						
$\mu(\text{cm}^{-1})$	1	0.4	0.225	0.376	0.700	2.740
	2	0.8	0.166	0.241	0.502	1.026
	3	1.3	0.130	0.185	0.384	0.667
	4	1.7	0.113	0.161	0.330	0.559
	5	2.5	0.0930	0.136	0.282	0.479
	6	6.1	0.0610	0.111	0.233	0.502
PARAMETERS FOR BUILD UP FACTORS: $B(\mu t) = A_1 e^{-a_1 \mu t} + (a - A_1) e^{-a_2 \mu t}$						
22 $-a_1$	1		0.119	0.098	0.098	0.030
	2		0.092	0.091	0.091	0.040
	3		0.0786	0.083	0.083	0.053
	4		0.0720	0.077	0.077	0.063
	5		0.0656	0.072	0.072	0.084
	6		0.059	0.0805	0.0805	0.177
a_2	1		0.008	0.009	0.009	0.305
	2		0.024	0.022	0.022	0.225
	3		0.0446	0.0355	0.0355	0.150
	4		0.052	0.044	0.044	0.117
	5		0.0686	0.0565	0.0565	0.088
	6		0.083	0.0585	0.0585	0.059
A_1	1		13.0	10.60	10.60	1.55
	2		10.3	9.15	9.15	2.30
	3		8.3	7.95	7.95	2.63
	4		7.0	7.20	7.20	2.68
	5		5.3	5.80	5.80	2.39
	6		3.1	3.05	3.05	.950

Integration of this expression from $\theta = 0$ to $\theta = \theta_1$ gives the flux from the upper half of the cylindrical source. To determine the flux from the entire source, with the dose point at the center plane of the source, this figure must be doubled. Thus:

$$\phi = \frac{R_o^2 S_v}{2 (a + z)} \left[A_1 \int_0^{\theta_1} e^{-b_4 \sec \theta} d\theta + A_2 \int_0^{\theta_1} e^{-b_5 \sec \theta} d\theta \right]$$

or

$$\phi = \frac{R_o^2 S_v}{2 (a + z)} \left[A_1 F(\theta_1, b_4) + A_2 F(\theta_1, b_5) \right]$$

Individual curves for each of the energy groups which represent the radiation from the bare Phoebus core attenuated through a concrete shield are shown in Figs. 7 through 14. The curve for the total dose through a concrete shield is shown in Fig. 15. The attenuation of the dose rate through barytes concrete is shown in Fig. 16. The attenuation through steel is shown in Fig. 17. An illustrative calculation of the attenuation through barytes is included. An important energy group not included in the core spectrum but arising from the (n, alpha) activation of the aluminum components is a 2.75 mev gamma from Na^{24} .

Although the total source strength from these activation gammas is two orders of magnitude below the source strength of the core, the energy of the gamma is sufficiently high to cause it to be an important contributor to the dose outside of a 5 ft concrete shield. A curve of the attenuation of a 2.75 mev gamma through concrete is shown in Fig. 18.

FIG. 7 DOSE RATE DUE TO 0.3 MEV GAMMAS AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE

FIG. 8 DOSE RATE DUE TO 0.7 MEV GAMMAS AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE

FIG. 9 DOSE RATE DUE TO 1.0 MEV GAMMAS AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE

FIG. 10 DOSE RATE DUE TO 1.5 MEV GAMMAS AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE

FIG. 11 DOSE RATE DUE TO 2.0 MEV GAMMAS AT 10 FT FROM
BARE PHOEBUS CORE SURFACE VS THICKNESS OF
ORDINARY CONCRETE

FIG. 12 DOSE RATE DUE TO 2.5 MEV GAMMAS AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE

FIG. 13 DOSE RATE DUE TO 2.8 MEV GAMMAS AT 10 FT FROM
BARE PHOEBUS CORE SURFACE VS THICKNESS OF
ORDINARY CONCRETE

FIG. 14 DOSE RATE DUE TO 3.5 MEV GAMMAS AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE

FIG. 15 TOTAL DOSE RATE AT 10 FT FROM BARE PHOEBUS CORE SURFACE VS THICKNESS OF ORDINARY CONCRETE (24 Hr After Shutdown)

FIG. 16 DOSE RATE AT 10 FT FROM SURFACE OF PHOEBUS CORE
VS THICKNESS OF BARYTES SHIELD
(24 Hr After Shutdown)

FIG. 17 DOSE RATE AT 10 FT FROM SURFACE OF PHOEBUS CORE
VS THICKNESS OF STEEL SHIELD
(24 Hr After Shutdown)

FIG. 18 ATTENUATION OF 2.75 MEV GAMMAS IN ORDINARY CONCRETE

DOSE IN THE CONTROL ROOM AND SHELTER AREAS FROM THE ENGINE BEFORE IT ENTERS THE MAIN DISASSEMBLY BAY

FUNCTION OF THE SHELTER AREAS

As the activated engine is transported from the engine test stand along the railroad (see Drawing 1425-C-2) and approaches the E-MAD building, the entire area must be evacuated. Personnel in the cold assembly bay and offices must go into a shelter area. Personnel located in the shielded control room, whose function is to observe and control the entrance of the engine into the main bay, are in shelter areas. The personnel in the shelter area should remain there until the front door of the engine disassembly bay is closed. A shelter area is provided in the cold assembly bay. In addition, the underpass from the east gallery to the west gallery beneath the hot hold tunnel (Area No. 10), is designated as a shelter area. The dose rate in Area No. 10, due to an engine outside the building, is negligible.

These shelter areas are necessary because the cold assembly bay and exterior gallery walls of the hot disassembly bay are unshielded and dose rates in these areas reach more than 100 r/hr, as the engine approaches the hot disassembly bay at 1 to 2 mph. When the engine gets within 2/3 of a mile of the main bay, the dose rate exceeds 2.5 mr/hr, and therefore personnel should take shelter. With the engine moving at its slowest anticipated speed of 1 mph the personnel need remain in the shelter area for less than an hour.

DOSE IN THE MASTER CONTROL ROOM AND SHELTER AREAS

As the engine approaches the main disassembly bay and personnel have been moved into the shelter area (see Drawing 1425-R-1 and 1425-R-3), the front door 122/1 of the main bay must be opened in order to admit the engine and to provide a shadow shield for the shelter area. This should be done when the engine is approximately one half mile from the E-MAD facility, to preclude excessive radiation level in Area No. 111 when the engine reaches the facility itself. When the engine is within 140 ft from the E-MAD building, the open front door shields the shelter area from the direct radiation of the

engine, therefore, only a scattered dose rate reaches the shelter area. When the engine reaches this point (140 ft), the distance from the engine to the shelter area is 280 ft and the dose rate in front of the shelter area is 40 r/hr. The north wall of the shelter area is 2-1/2 ft thick. The radiation from the engine is incident on the wall at an angle of 18° with the normal. Thus the effective thickness of the wall is 31.5 in. This provides an attenuation of 5×10^{-4} . Therefore, the maximum direct dose rate from the engine through the front wall of the shelter area, which occurs only when the engine is about to pass behind the open door of the main bay, is 20 mr/hr. The side walls and roof of the shelter area are based on the scattered dose rate from the engine. To determine the concrete thickness required for these walls, the following equation derived by Epstein and Geller* is applied.

$$D_S = \frac{1.9 \times 10^{-6}}{2 \pi R} \sum_E \sum_{0}^{90^\circ} S_E h_E (a, \mu R)$$

D_S = dose, r/hr

1.9×10^{-6} = factor to convert mev/(sec)(sq cm) to r/hr

R = distance from source to dose point, cm

S_E = source strength, mev/sec

h_E = $(d, \mu R) C$, equation 7, page 6 of paper by Epstein and Geller* and curves in the paper which plots this function.

a = angle from vertical to point of scatter

μ = linear absorption coefficient for air**

E = energy group

* "A General Method for Evaluating Containment Shielding Under Normal and Emergency Conditions" by R. Epstein and L. Geller, Vitro Engineering Company, presented at the Second International Conference for the Peaceful Uses of Atomic Energy, Geneva, Switzerland.

** Page 37 of APEX-176 by Moteff.

This paper by Epstein and Geller presents an approach to scattering developed by Vitro for the shielding design of the Consolidated Edison reactor at Indian Point. The assumptions implicit in this equation are as follows:

1. The source is isotropic.
2. The presence of the ground is not considered in reducing the scattered dose rate.
3. After scattering, all photons penetrate the shield normally, along the shortest path. This is quite conservative as it does not take advantage of slant penetration.
4. The source strength from the engine is a factor of 3.8 less than the source strength from the unshielded core.
5. The door to the main bay (122/1) is open during the last half mile of the approach of the engine to the main bay.

The scattered dose is highest when the engine is 20 ft from the main bay door opening. At this time the engine is 150 ft from the shelter area. The scattered dose rate at the shelter area prior to its attenuation through the shelter area walls with the engine at this distance is 7.5 r/hr at an effective energy of 0.3 mev. The attenuation factor required from the wall for these gammas is 300, therefore a concrete thickness of 14.5 in. is required. The front wall, which has been sized for the direct dose 280 ft from the shelter, is 2.5 ft thick. Once the engine gets closer than this, the dose in the shelter is all due to scattered radiation. The east wall of the shelter area has been conservatively sized at 18 in. thick. The roof of the shelter area is 1 ft thick. However, the roof of the room directly above the roof of the shelter area is 4.5 in. thick, making a total concrete thickness of 16.5 in. This exceeds the required thickness. The radiation which scatters below this second roof has been calculated and contributes negligibly to the dose. The thickness of the west wall of the shelter area is 14 in. However, for radiation to penetrate this wall, it must have made several scatters. Therefore, the thickness of this wall is conservative.

It may be seen, therefore, that the maximum level of radiation from the shelter area is reached when the engine is 280 ft from the shelter, just before the shadow shield of the front door is interposed between the

shelter and the engine. The direct dose at this point is 20 mr/hr and the scattered dose at this point is <5 mr/hr. As the engine approaches the main bay, and the front door blocks the direct radiation from the engine, the dose rate falls off to approximately 5 mr/hr, and increases to <20 mr/hr before the engine enters the main bay.

If the engine is moving at a speed of 1 mile/hr, the integrated dose in the shelter area is <2 mr.

The dose rate in the control room is lower than this, because the working station is protected by 6 ft thick concrete walls facing the inside of the main bay. A small section of 2 ft 6 in. thick wall, projecting into the west gallery, facing the front of the building serves to extend the width of the control room. The west wall of this room is 18 in. thick; the rear wall is 1 ft thick. A 2 in. thick steel door is provided to attenuate the back scattered gammas streaming down the gallery, which might otherwise backscatter into the control room.

DOSE RATES IN THE OPERATING GALLERIES

MAIN BAY

Direct Dose From Core

The dose rate from the core through 5 ft of concrete at the centerplane of the core, is 48 mr/hr, with the core 10 ft from the dose point (see Fig. 15) . The ratio of the core dose rate to the engine dose rate, without accounting for aluminum activation, is 2.9 through the 5 ft concrete wall. Thus the dose rate due to the source at 10 ft from the dose point through the 5 ft concrete wall 24 hr after shutdown is 16.5 mr/hr. The dose, calculated by integrating the dose rate from the engine over a 40 hr week, is $16.5 \times 11 = 182$ mr/wk. However, the height of the core while still in the engine, is not expected to be below 11 ft from the floor nor more than 120 ft from the floor. With the core still in the engine and the engine at its closest possible distance to the main bay wall (the core surface 5 ft from the wall) the dose rate at the hottest point in the upper and lower galleries, does not exceed 70 mr/wk (see Fig. 19 and Table 4) .

Direct Dose From Activated Engine Parts

The sources for the activated engine parts are listed in Table 2. The sum of the dose rate from each aluminum part multiplied by its confidence factor establishes a total dose rate from all aluminum parts of 7.6×10^5 mr/hr, 10 ft from the source point, 24 hr after shutdown. Of this dose, according to Aerojet General (who provided the source strengths for the engine parts), and Westinghouse (who provided the source strength for the core parts), 60% is to be considered at 2.75 mev and 40% at 2.0 mev. Thus the 2.75 mev dose is 4.6×10^5 mr/hr and the 2 mev dose from aluminum is 3.0×10^5 mr/hr. Calculated in the same manner the 2 mev dose from the steel and the non-aluminum parts is 2.3×10^5 mr/hr.

However, these figures do not include the effect of self shielding of the parts or the effects of shielding by the parts behind the core by the core itself. This self shielding factor has been conservatively estimated by

FIG. 19 ELEVATION OF MAIN DISASSEMBLY BAY SHOWING TYPICAL GAMMA PATHS FOR CALCULATING DIRECT AND SCATTERED DOSES

TABLE 4 - DOSE RATE IN GALLERIES AROUND MAIN BAY FROM PHOEBUS ENGINE,
STARTING 24 HR AFTER SHUTDOWN

Dose Location	Source and Location (Hot Bay Floor Elevation = 101 ft)	Direct Dose From Engine		Roof Scatter Dose, Based on Bare Core		Scatter Dose from Stepped Portions of Upper Bay, Based on Bare Core		Dose from Activated Engine Parts		Total Dose - Phoebus		Total Dose - Nerva ³	
		Initial ¹ (mr/hr)	Weekly ² (mr/wk)	Initial (mr/hr)	Weekly (mr/wk)	Initial (mr/hr)	Weekly (mr/wk)	Initial (mr/hr)	Weekly (mr/wk)	Initial (mr/hr)	Weekly (mr/wk)	Initial (mr/hr)	Weekly (mr/wk)
Upper Gallery behind 5 ft wall Dose point at elevation 124 ft	Engine 5 ft from wall Top of core at elevation 118 ft*	1.7	19	1	11	0.1	1.1	0.4	3.9	3.2	35	0.96	11
Upper Gallery behind 5 ft wall Dose point at elevation 124 ft	Engine 5 ft from wall Top of core at elevation 120 ft**	5	55	1	11	0.1	1.1	1.0	10.0	7.1	77	2.1	23
Upper Gallery behind 5 ft wall Dose point at elevation 124 ft	Engine 45 ft from wall Top of core at elevation 120 ft	0.25	2.8	1	11	1.2	13.2	0.05	0.52	2.5	27	0.75	8
Lower Gallery behind 5 ft wall Dose point at elevation 107 ft	Engine 5 ft from wall Bottom of core at elevation 111 ft	5	55	0.4	4.4	0.04	0.4	1.0	10.0	6.4	70	1.9	21
Lower Gallery behind 5 ft wall Dose point at elevation 104 ft	Engine 5 ft from wall Bottom of core at elevation 101 ft†	16.5	182	0.4	4.4	0.04	0.4	3.5	34.8	20†	221†	6†	65†
Lower Gallery behind 5 ft wall Dose point at elevation 104 ft	Engine 11 ft from wall Bottom of core at elevation 101 ft†	7.4	81	0.4	4.4	0.08	0.9	1.6	16.0	9.5†	102†	2.9†	31†
Lower Gallery behind 6 ft wall Dose point at elevation 104 ft	Core 4 ft from wall Bottom of core at elevation 101 ft	2.5 (Core)	28	0.4	4.4	0.04	0.6	0	0	2.9	33	0.9	10
Lower Gallery behind 5 ft wall Dose point at elevation 104 ft	Core 22 ft from wall Bottom of core at elevation 101 ft	8.2 (Core)	90	0.4	4.4	0.2	2.2	0	0	8.8	93	2.6	29

¹ Initial dose rate is dose rate from a core or engine 24 hr after reactor shutdown.

² Weekly dose is dose accumulated over five 8 hr shifts, spaced 1 day apart, starting 24 hr after reactor shutdown.

³ Because this facility is to be used for Nerva, these figures have been included for comparison.

* Core height of 17 ft, corresponding to maximum elevation specified by Aerojet.

** Core height of 19 ft, included for reference to illustrate that the core may be at a higher elevation and still not exceed the weekly dose rate of 100 mr/hr.

† These source locations are included for reference. However, when the core is part of the engine it is not possible for the core to be at floor elevation. Therefore, these high dosages cannot be realized from the engine.

NOTE: Due to the inherent approximations made in shielding calculations, figures in the table may be valid to one significant figure. However, they are presented to several figures to preserve comparison with the text.

Aerojet as 0.5. Thus, the dose spectrum 10 ft from the engine, from the activated engine parts, 24 hr after shutdown is as follows:

$$2.3 \times 10^5 \text{ mr/hr at } 2.75 \text{ mev}$$

$$2.7 \times 10^5 \text{ mr/hr at } 2 \text{ mev}$$

The attenuation of 2.75 mev gammas through 5 ft of concrete is 1.5×10^{-5} (see Fig. 18). Therefore, the dose due to activated aluminum, 24 hr after shutdown, through a 5 ft thick concrete wall, with a source to dose point separation of 10 ft, is 3.5 mr/hr. The integration factor for aluminum, as derived from Fig. 6 of this report is 3.28 for a 40 hr week, spaced in 8 hr shifts, one day apart. Thus, the contribution of this source, integrated over a 40 hr week, is 11.5 mr/wk.

The attenuation of the 2 mev gammas through 5 ft of concrete is 2.1×10^{-6} (see Fig. 11). Therefore, the 2 mev dose rate due to activated steel and core parts 24 hr after shutdown is 0.57 mr/hr. This is <4% of the total dose from the engine. Without the uncertainty factor it would be ~ 0.4%. In addition, the half life of the 1 to 2 mev gammas from elements in the steel with the largest activation cross section is short.

It is seen that the 2 mev gammas from activated parts do not contribute significantly to the total dose from the engine. However, the 2.75 mev gammas from aluminum do make a significant contribution. The calculated doses are tabulated in Table 4.

Physical Location of the Core While Part of the Engine

It is assumed that the dose point is at the midplane of the core to arrive at the curves shown in Fig. 7 through Fig. 17. However, this is an idealized assumption. This situation does not normally exist when the core is in the engine because of the relationship between the gallery height and the core height (see Fig. 19). The maximum core height in the engine configuration, as specified by Aerojet, is 17 ft above the floor of the main bay. This places the top of the core approximately 6 ft below the lowest critical dose point represented by a man standing in the upper gallery. A core height of 19 ft has also been considered, to illustrate that the core may be at a higher elevation than that specified, without exceeding the weekly dose rate design criterion of 100 mr/wk. The lowest point for

the bottom of the core is defined by the height of the core above the nozzle (assumed rather than actual to avoid revealing specific classified dimensions). At this lowest point the core is located several feet above the head of a man standing in the lower gallery. Fig. 19 shows the approximate range for the position of the core. Calculated dose rates are presented in Table 4.

The bare core could be as low as floor level. Thus the centerplane of the core could intersect a man standing in the lower gallery. Therefore, the dose rate from the core is based on penetration normal to the wall. The result obtained by using the infinite slab shield equation is conservative because the buildup factor is based upon the wall being infinite below as well as above the core. In reality, the presence of the floor below the core would reduce the buildup factor. No reduction in dose has been attributed to this effect.

Scattered Dose Rate

In addition to the direct dose rate through a shielding wall, there is an additional contribution to the dose from gamma rays which escape through thinner portions of the main bay wall or the roof and scatter to the dose point. The scatterer may be air or the thinner wall itself.

Scattered Dose Rate from Stepped Upper Portions of Main Bay Wall

The equations used to calculate the dose rate in the galleries outside the main disassembly bay are based upon a uniform wall thickness. However, in order to reduce the weight of the concrete walls, and to provide steps in the walls for the crane rails, the thickness of the upper portions of the walls is reduced. The thicknesses of these stepped back walls are based upon structural as well as shielding considerations.

In order to determine the permissible reduction in thickness, equations have been derived to calculate the dose rate in the galleries and at the ground due to the scattered dose from gammas penetrating the reduced wall thickness. The equation used to calculate the dose from each section of wall is as follows:

$$D = 2 \sum_{E=1}^{E=8} \frac{I_0(E)}{R_2^2} \left[A_1 \int_{\phi_1}^{\phi_2} e^{-(1+a_1)b \sec \phi} d\phi + \right. \\ \left. (1 + A_1) \int_{\phi_1}^{\phi_2} e^{-(1+a_2)b \sec \phi} d\phi \right] \times \frac{\theta_1 - \theta_2}{360} \times \\ \left[\frac{1}{1 + \frac{E_0}{0.51} (1 - \cos \theta)} \right] G(E) \times \frac{1}{\sigma_s(E)} \times \frac{d\sigma}{d\Omega}$$

- where
- D = scattered dose rate
 - $I_0(E)$ = source strength of bare Phoebus core 24 hr after shutdown, mev/sec
 - E = gamma energy group
 - R_2 = distance from scattering surface to dose point
 - A_1, a_1, a_2 = parameters defining the buildup factor as:
 $B(E, \mu t) = A_1 e^{-a_1 \mu t} + (1 + A_1) e^{-a_2 \mu t}$
 - b = linear absorption coefficient x normal thickness of shield = μt
 - ϕ = horizontal angle subtended by scattering surface
 - θ = angle between normal to wall and path of incident radiation in a vertical plane
 - $G(E)$ = conversion of mev/(sq cm)(sec) to mr/hr
 - $\sigma_s(E)$ = scattering cross-section per electron
 - $\frac{d\sigma}{d\Omega}$ = differential Klein-Nishina cross section/electron, defined as:

$$\frac{d\sigma}{d\Omega} = \frac{e^4/m^2 C^4}{2} (P - P^2 \sin^2 \phi + P^3)$$

$$\text{where } P = \frac{1}{1 + \frac{E_0}{0.51} (1 - \cos \theta)}$$

In the equation, the parameters in the square brackets give the attenuation and buildup for each energy group integrated between the horizontal angle from ϕ_1 to ϕ_2 for slant penetration of unscattered gammas through the wall. $(\theta_1 - \theta_2)/360$ gives the fraction of the source gammas which intercept the horizontal slice of wall being considered; this would be $(\theta_1 - \theta_2)/180$ except for the factor of 2 preceding the source term. The second term in square brackets yields the degradation in energy for a single scattering event and the ratio of cross sections, $d\sigma/d\Omega$ divided by $\sigma_s(E)$ gives the ratio of the gammas which scatter into the solid angle Ω divided by the number of gammas which scatter in all directions, for each energy group.

The foregoing equation gives conservative results because it embodies the following assumptions:

1. All gammas which penetrate the wall undergo a scattering collision, with a probability, defined by the Klein-Nishina cross section, of scattering into a solid angle including the dose point.
2. Scattering occurs after the radiation has traversed the wall with a slant penetration. There is no attenuation of the scattered radiation by the wall itself. This has been compared with a scatter occurring on the inner face of the wall and the gamma traversing the wall normally and scattering again to the dose point. For the geometries under consideration, the former assumption has been used as it gives the higher dose rate.
3. The source for the scatter calculations is the bare core. No credit is taken for the attenuation afforded by the engine structure. The elevation of the core has been taken as 17 ft above the floor of the bay.
4. No attenuation is attributed to the roofing material of the upper gallery.

The dose rate in the upper operating gallery due to gammas which have penetrated the thinner sections at the upper portion of the main bay wall is 1.2 mr/hr, when the engine is 45 ft from the wall. As the engine approaches the wall, the dose rate decreases because of the reduced

subtended angle $\theta_1 - \theta_2$, and the increase in slant penetration. The concrete crane rail brackets also serve to reduce the dose when the engine is close to the main bay wall. With the engine 5 ft from the main bay wall, the dose rate contribution from the stepped back portion of the main bay is <0.1 mr/hr. These dose rates are shown in Table 4.

The concrete floor of the upper operating gallery serves to shield the lower operating gallery. The average energy of the scattered gammas incident on this floor is 0.3 mev. The dose rate in the lower gallery from the above source ranges from 0.04 mr/hr to 0.5 mr/hr as a function of engine position. The low dose is obtained with the core 5 ft from the surface of the wall and the high dose is obtained with the core 61 ft from the surface of the wall.

Calculation of Roof Thickness

The core may be considered an isotropic source located in the center of the bay. In the geometry shown below, the roof is considered an infinite slab, having thickness, a . The distance from the core to a point above the roof is d , and the gamma flux over a differential area dA is calculated as follows:

$$d\gamma_T = \frac{S d A \mu x e^{-\mu x}}{4\pi R^2}$$

where:

$$\begin{array}{ll} S & = \text{source for each energy} & r & = d \tan \theta \\ dA & = 2\pi r dr & dr & = d \sec^2 \theta d\theta \\ R & = d \sec \theta & a & = \text{roof thickness} \\ X & = a \sec \theta & \mu & = \text{mass absorption coefficient} \end{array}$$

$$\gamma_T = \frac{S}{4\pi} \int \frac{2\pi d^2 \tan \theta \sec^2 \theta d\theta \mu a \sec \theta e^{-\mu a \sec \theta}}{d^2 \sec^2 \theta}$$

Change variable so that $\mu a \sec \theta = v$

$$\text{then } dv = \mu a \tan \theta \sec \theta d\theta$$

$$\text{and } d\theta = dv / \mu a \tan \theta \sec \theta$$

Thus:

$$\gamma_T = \frac{S}{2} \int_{\mu a}^{\infty} e^{-v} dv = \frac{S}{2} e^{-\mu a}, \text{ or, for a finite roof, } S e^{-\mu a} \Omega_R$$

where Ω_R = fractional solid angle subtended by the roof.

This term yields the total gamma flux which emerges from the roof. The dose on the ground, due to this gamma flux scattered by the air is calculated conservatively by:

$$D = \left[\frac{S_v G}{h^2} \right] \left[e^{-\mu a} \frac{d\sigma(\theta)}{d\Omega} \frac{1}{\sigma_s} \right] \left[\frac{1}{1 + \frac{E_0}{0.51} (1 - \cos \theta)} \times \Omega_R \right]$$

where

$$\begin{array}{ll} S_v & = \text{source, mev/sec} \\ G & = \text{conversion of mev/(sq cm)(sec) to mr/hr} \\ h & = \text{distance from scattering volume to dose point} \\ \mu a & = \text{linear absorption coefficient x thickness of roof} \\ \frac{d\sigma(\theta)}{d\Omega} & = \text{Differential Klein-Nishina cross section} \\ \sigma_s & = \text{Total scattering cross section} \\ \theta & = \text{scattering angle} \\ E_0 & = \text{initial gamma energy before scattering} \end{array}$$

This equation gives a conservative result, because of the assumption implicit in it. These assumptions are:

1. the scattering takes place in the air volume which gives the highest dose on the ground.
2. a linear buildup factor $B = \mu a$ is employed for attenuation through the roof. This makes the differential explicitly integrable.
3. The integrated source terms $1/2 S e^{-\mu a}$ that results from the above derivation is the total radiation that would pass through the roof if the roof were an infinite slab. This assumption is conservative.
4. The source for the scatter attenuation is the bare core. No credit is taken for attenuation afforded by the engine structure. The elevation of the core was taken as 17 ft above the floor of the bay.
5. Attenuation through the roof of the upper gallery is neglected.

Application of the equation gives a dose rate of <1 mr/hr on the ground for a 2 ft 9 in. roof thickness. The dose rate in the upper gallery from air scatter above the roof of the bay is approximately 1 mr/hr, due to gammas with an average energy of 0.3 mev. The dose rate from this scatter source is fairly insensitive to the position of the core in the bay. The maximum dose, which occurs with the core in the center of the bay, has been taken as the basis of calculation. The effect of this scatter dose on the total dose is shown in Table 4.

The initial dose rate on top of the main bay roof directly over the bare core will be 1.2 R/hr. Thus a man may be on the roof for emergency maintenance for 5 minutes with a fresh core in the main bay before he receives a dose of 100 mr/hr. This time may be extended substantially if the work on the roof is being done away from the area directly over the bare core.

Safety Factors

There are many assumptions implicit in the calculations which tend to overestimate the dose rates, and therefore make the design conservative. The total effect of these conservative features may be considered as a safety factor. The conservative approximations directly affecting the equations, have been discussed earlier and are not repeated here. The assumptions, that tend to make the design conservative are as follows:

1. The facility has been designed for Phoebus, although it will be used initially for Nerva.
2. The earliest time after shutdown that the engine can be brought into the main bay from the test stand is 24 hr after shutdown, because the engine requires forced decay heat cooling at the test stand prior to this time. However, all operations are assumed to take place 24 hr after shutdown, including those involving the bare core. This assumes that it takes zero time to detach the engine from the test stand and bring it into the main bay. It also assumes that the bare core can be exposed in zero time.
3. The integrated dose is predicated on the same man being at the hottest point in the gallery for his entire working week, for 50 wk/yr.
4. The integrated dose calculation makes the highly conservative assumption of one freshly fired engine entering the facility each week.
5. The concrete density employed in the calculations is 144 lb/cu ft. The concrete density specified for construction is 150 lb/cu ft. In addition, there is a substantial amount of steel in the ordinary concrete in the form of reinforcing rods. For example in the 5 ft main bay walls on the inside face, there are 1.410 in. reinforcing rods running vertically, spaced 4 in. apart on centers and 3/4 in. reinforcing rods spaced 1 ft apart horizontally. On the outside face there are vertical rods 1.140 in. on 8 in. centers plus 3/4 in. horizontal rods on 1 ft centers. In effect, 43% of the wall area includes steel

with an average thickness of over 1 in. In the 3 ft 6 in. portion of the wall 75% of the area includes steel over 1 in. thick, and in the 2 ft 6 in. portion of the wall 75% of the area includes steel with an average thickness of over 2 in. The roof includes a 60% steel area with over a 1 in. average steel thickness.

No credit is taken in the calculations for any of this steel.

6. No credit is taken for the shielding of the core by the engine structure above the core for the scattering calculating through the roof and the upper portions of the main bay.
7. It should be noted that the dose rates for the engine or the core, shown for different engine positions are not additive at a given dose point. That is, the dose rates are for the point at which the source creates the greatest dose. Therefore, two engines or cores could be at different places in main bay without causing excessive doses at any one point.
8. A full inventory of fission products has been assumed for the core. Actually there will be losses (estimated as high as 7%) of fission products from the core during firing of the engine.
9. The calculated activation doses have been multiplied by their "confidence factors" to establish the maximum doses from the engine parts.
10. The shielding windows have been designed to attenuate the dose from an engine or core directly in front of them to 1 mr/hr. Thus, if it is deemed desirable to reduce the initial dose rate from a fresh source to <2.5 mr/hr at any one window, local shielding can be placed around this window.

CORE DISASSEMBLY CELLS

There are five areas designed to shield an entire bare Phoebus core, 24 hr after shutdown: the southwest portion of the main bay, the crane maintenance balcony, the east and west core and engine disassembly cells, and the engine hold tunnel.

The main bay walls in the southwest portion of the building are 6 ft thick to provide an area in the main bay where the bare core can be brought close to the operating gallery wall.

The walls of east and west core and engine disassembly cells are also 6 ft thick. They attenuate the radiation from a Phoebus core, 24 hr after shutdown, to 2.5 mr/hr, with a core 4 ft from the inside surface of the cell walls (see Fig. 19). As the core itself is disassembled, there results a maximum increase in dose rate by a factor of 3 (approximately) due to a loss of self-shielding. However, the disassembly can not be achieved within a few hours after the engine is brought into the main bay, and it is estimated that 2.5 days would be required to achieve the actual disassembly of a hot core. Within 2 days the dose rate is lowered by a factor of 3 due to decay of the source, therefore the dose rate in the core disassembly cells should not exceed 2.5 mr/hr, even from a disassembled core.

The roof of the east and west core disassembly cells is 6 ft thick under the gallery around the crane maintenance balcony. Where a greater height is required the roof consists of 4 ft thick barytes concrete, which is equivalent to 6 ft of ordinary concrete.

The balcony is also designed to hold a full core. Its walls are 6 ft thick from the floor (at elevation 136) up to elevation 151 ft 4 in. From elevation 151 ft 4 in. to elevation 164 ft 5 in. the concrete is 4 ft thick, with a 5 ft 6 in. thick section jutting into the balcony from elevation 161 ft 4 in. to elevation 164 ft 5 in. From elevation 164 ft 5 in. to the junction with the roof, at an elevation of 175 ft 6 in. the wall is 3 ft thick. The upper two wall thicknesses are reduced to 4 ft and 3 ft respectively to accommodate the crane rails. These thicknesses are adequate because of the combined effects of slant penetration and distance attenuation. The physical construction is similar to the one that prevails in the main bay, except that the elevation of the step in the wall

is lower with respect to the core and a man in the operating gallery. Because of this the dose rate to a man in the gallery due to scattering through the upper wall sections is <2 mr/hr with the core at a distance of 4 ft to 10 ft from the inside wall surface and <4 mr/hr with the core at a distance of 22 ft from the inside wall surface. However, the direct dose with the core 22 ft from the wall is 0.4 mr/hr. The roof over the balcony is 3 ft thick, and despite the higher elevation of the core, attenuates the dose rate to a man in the gallery to a slightly greater extent than does the 2 ft 9 in. roof over the main bay, producing a dose <1 mr/hr.

The total dose to a man in the gallery from a bare core, 24 hr after shutdown, is approximately 5 mr/hr with the core 4 ft from a 6 ft thick wall, and a maximum of 6 mr/hr, 24 hr after shutdown with the core 22 ft from a wall to yield integrated doses of 55 mr/wk and 66 mr/wk respectively. However, it is extremely doubtful that a bare Phoebus core could be brought into the balcony 24 hr after reactor shutdown. If it were brought in 2 days after shutdown the maximum initial dose rate from the direct and scattered dose would be 2 mr/hr.

ENGINE HOLD TUNNEL

The engine hold tunnel is designed to store either an entire engine or a bare core, in order to gain access to the main bay for maintenance operations, or to bring an engine or core into either one of the two disassembly cells adjoining the tunnel. In addition, a core can be lowered directly from the crane maintenance balcony into the engine hold tunnel.

There is an operating gallery with a window in the north portion of the engine hold tunnel. The wall thickness of the tunnel in this area is 6 ft of ordinary concrete to reduce the dose rate from a bare core to the unlimited access operating gallery to 2.5 mr/hr.

The engine hold tunnel itself is a limited access area, with a maximum dose rate of 25 mr/hr permitted from sources in areas adjacent to the engine hold tunnel. Therefore, the walls between the tunnel and the core and engine disassembly cells are 5 ft thick.

The roof thickness of the engine hold tunnel is 6 ft thick under the operating gallery of the crane maintenance balcony, matching the roof thickness of the disassembly cells under the gallery. The roof thickness under the crane maintenance balcony, which is also a limited access area is 4 ft 8 in. of ordinary concrete. This is based upon a permissible dose rate, in either of the two areas, of 25 mr/hr from a bare core, 24 hr after shutdown. The source to dose point distance separation in this area is 25 ft due to the height of the tunnel, which in itself provides an attenuation factor of > 0.2 . The dose rate in the balcony from a fresh bare core with its top surface 10 ft above the tunnel floor has been calculated to be 25 mr/hr; the dose rate in the tunnel from a bare core on the floor of the balcony 20 mr/hr. However, it is highly improbable to have a bare core in either of these positions within 24 hr after shutdown and the dose rates would be lower by a factor of 3 to 4 after an elapsed time of 2 to 3 days (after shutdown).

COUNTING ROOM

A counting room is provided in the cold bay (Area 107 on Drawing 1425-R-1). This area also serves as an additional shelter from an approaching engine.

The dose rate in this area, in the absence of local shielding, could be as high as 0.2 mr/hr, due to a fresh core in the east core disassembly cell. In order to provide a low background, this room is shielded with 18 in. of concrete. This reduces the background dose rate to $< 3 \times 10^{-3}$ mr/hr.

LOCAL SHIELDING

DOORS

Personnel Doors (122/3, 122/4, 306/1, and 306/2)

The personnel doors (shown in Drawing 1425-L-18) are the means of entrance and egress to the main bay, and the crane maintenance balcony. Each pair of doors consists of two steel encased stacks of lead bricks, one on either side of the opening. The use of two separate doors reduces the weight of each door and provides an air lock. For each door the thickness of the lead is 8 in.; the steel casing on each side of the lead is 1/2 in. thick.

The attenuation through each pair of doors is equivalent to the attenuation of a 5 ft thick concrete wall. The door opening is 4 ft wide and 7 ft high. The door height is 7 ft 10 in. providing a 6-5/8 in. overlap on top and a 3-3/8 in. overlap on the bottom. The overlap on each side of the door opening is 9 in. In addition, there is a lead lintel, 6 in. thick and 14 in. deep, at the top and sides of the door openings, to prevent radiation from streaming through the thin portions of the concrete at the corners of the door opening. Without this lead lintel the doors would have to be substantially wider and higher to provide adequate overlap.

Main Disassembly Bay Door (122/1)

The main disassembly bay door serves to admit the complete engine on a railroad car into the main disassembly bay. The door opening is 22 ft wide and 37 ft high. The door itself is 39 ft 9 in. high and 26 ft wide. On the west side, the door in its closed position mates with the wall in a zig-zag baffle to prevent radiation streaming. There is an L-shaped overlap on the east side which also serves to prevent radiation streaming.

The thickness of the main disassembly bay concrete door is 5 ft. Two 1/2 in. steel plates sheathe the inner and outer face of the door up to a height of 14 ft 6 in. At a height of 28 ft, corresponding to an elevation of 129 ft, a lighter concrete aggregate is used in the door, to reduce its over-all weight. Thus the concrete density is 100 lb/cu ft from elevation

129 ft to 139 ft and 150 lb/cu ft from elevation 101 ft to 129 ft. A 5 ft thickness of ordinary (150 lb/cu ft) concrete and 1 in. of steel would attenuate the dose rate to 8 mr/hr outside the door, with the core surface at a distance of 5 ft from the inside of the door, the dose point being taken at the centerplane of the core when the core is part of the engine. However, the highest elevation of a dose point outside the door was taken as 6 ft, corresponding to the height of a man. This is below the elevation of the centerplane of the core at its lowest elevation while part of the engine. The increased effective wall thickness due to slant penetration reduces the direct dose from the engine to 2.4 mr/hr. With the top of core at a height of 17 ft above the floor of the main bay, corresponding to its highest anticipated height, the gamma scattering through the upper portion of the door where low density aggregate is employed contributes approximately 2 mr/hr to the dose rate outside the door, 6 ft above the ground. As the engine is moved away from the door, the contribution to the dose through the lower portion decreases, while the contribution through the upper portion increases. However, the contribution through the upper portion never exceeds 4 mr/hr, while the contribution through the lower portion drops off as a function of distance as shown in Fig. 3.

Door to Engine Hold and Transfer Tunnel (122/2)

This door serves to shield personnel doing maintenance work in the hold and transfer tunnel while a hot engine is in the main bay, and to protect personnel doing maintenance work in the main bay while the hot engine has been transferred to the tunnel. Both of these areas are designed for limited access. Therefore, the permissible dose rate from a fresh engine is 25 mr/hr. Door 122/2 is made of high density concrete and is 3 ft 7 in. thick. With a bare core on one side of this door, a man on the other side 10 ft from the fresh core (24 hr after shutdown) would receive a dose rate of 20 mr/hr. This may be seen in Fig. 16. If the source were a fresh engine, the dose rate would be 7 mr/hr. If a man is further from the source than this 10 ft distance, the dose rate falls off with a somewhat less than an inverse square attenuation, as shown in the function plotted in Fig. 3. The dose rate is <25 mr/hr to allow for contributions from other sources such as a core in the balcony plus a core in the main bay while a man is in the engine hold tunnel, or a core in the engine hold tunnel plus a core in the balcony while a man is in the main bay close to door 122/2. The calculations are conservative because the door has been treated as an infinite slab in the equations.

Its actual size subtends a smaller solid angle of radiation from the core, thus reducing the actual buildup. No credit has been taken for this in the calculation.

The door is 30 ft 9 in. high, covering a door opening 29 ft high, and has an interlocking overlap on each side. The door is also stepped in the center where the two halves join. These precautions prevent any additional dose due to streaming.

Exit Door from Hold and Transfer Tunnel (128/1)

This door, shown in Drawing 1425-L-7, provides a means to transfer hot parts from the engine hold tunnel to the small hot cells for core and engine parts. The cells south of this door form a part of the Phase II design. If the facility were built without the Phase II design this door would provide a rear exit for radioactive parts from the facility. The door consists of 20 in. thick steel. The dose rate through this door from a bare core separated 10 ft from the dose point would be 21 mr/hr. This may be seen on Fig. 17 which shows the dose rate from the bare core as a function of a steel shield thickness. Normally, however, a core would be no closer to this door than is required for it to pass into the core and engine disassembly cells and, therefore, would be no closer than 35 ft from the door. The dose rate outside the door with the core at this distance would be 2.1 mr/hr. The channels for the rollers on which this door rides are lead filled to provide an attenuation equal to that of the steel thickness of the door, thus preventing streaming from under the door. The vertical and lateral overlap of the door, over the door opening, provides adequate protection against scattering or streaming through the edges of the wall.

Doors to the Core and Engine Disassembly and Examination Cells (127/1 and 130/1)

These doors separate the core and engine cells from the hot hold tunnels. They consist of 20 in. thick steel. As noted above, the attenuation through a 20 in. steel door with a source to dose point separation of 10 ft yields a dose rate from a bare core of 21 mr/hr. Both the core and engine disassembly cells and engine hold tunnel are limited access areas and the maximum design dose rate is 25 mr/hr. The doors are 14 ft wide and cover an 11 ft wide opening, thus providing an 18 in. overlap on each

side. Lead is provided in the channels for the rollers, thus preventing streaming of radiation under the door; the door is 18 ft high, providing a 6 in. overlap at the top.

East and West Doors to the Crane Maintenance Balcony (306/3 and 306/4)

The function of these doors is to protect a man in the main bay from the radiation due to a core in the balcony, or conversely to protect a man in the balcony from the radiation due to a core in the main bay. Both the balcony and the main bay are classified as limited access areas, with a limit of 25 mr/hr (maximum) on the dose rate from a fresh core.

The east door, shown on Drawing 1425-L-5, is 4 ft thick, composed of concrete having a density of 150 lb/cu ft up to an elevation of 160 ft and concrete having a density of 100 lb/cu ft from an elevation of 160 ft to the top of the door at an elevation of 170 ft 6 in. The bottom of this door is 13 ft 8 in. from the floor of the balcony. The door rests on a 4 ft thick wall of ordinary (150 lb/cu ft) concrete. The bottom of this door is several feet higher than the top of the core. This, plus the provision of steel slabs at the bottom of the door prevents gamma ray streaming under the door. This door attenuates radiation passing through it with a slant penetration with respect to a man in the main bay.

The west door, shown on Drawing 1425-L-3, is 4 ft thick, composed of ordinary concrete having a density of 150 lb/cu ft from elevation 136 ft to elevation 160 ft. From elevation 160 ft to 173 ft 9 in. it is composed of light concrete having a density of 100 lb/cu ft. The profile of this door matches the profile of the east door combined with the wall underneath it, and provides the same attenuation. The west door meets the east door in a stepped configuration to prevent streaming. Steel is provided above and below both doors to attenuate the radiation which might otherwise stream through the mechanism supporting the door.

The attenuation through the slab shield composed of both the east and west crane maintenance balcony doors is treated as if the doors were a single unit.

The direct dose from a core in the balcony to a man in the main bay must be based upon: a slant penetration through the concrete; a normal penetration through the concrete with an air scatter to a man on the floor of the

main bay; or a slant penetration through the light concrete in the upper portion of the doors with a scatter off the roof of the main bay down to a man on the floor or the main bay.

The direct dose is strongly a function of the position of a man in the main bay. If a slant penetration of 30° from the normal is considered a man on the floor of the main bay would be over 60 ft from the core, and the direct dose would be 5 mr/hr. If a slant penetration of 45° is considered, a man on the floor of the main bay would be over 40 ft from the core and the direct dose would be approximately 0.5 mr/hr.

The scatter dose is assumed to come from both air scatter and roof scatter. The gammas which penetrate the shield normally, and air scatter to the dose point would contribute a dose of < 10 mr/hr; the gammas passing through the upper, 100 lb/cu ft, portion of the concrete doors would contribute < 5 mr/hr.

This latter number is based upon the following equation for radiation scattered from a thick slab:

$$I = \frac{6.03 \times 10^{23} \rho Z I_0 C}{AX^2 \left[\mu_1 + \mu_2 (\cos \theta_1 / \cos \theta_2) \right]} \frac{d\sigma}{d\Omega}^*$$

where

- ρ = density of the concrete slab = 2.3 gm/sq cm
- Z = atomic number of scatterer
- A = atomic weight of scatterer
- I_0 = intensity of the incident beam
- I = intensity of the scattered beam
- C = cross sectional area of incident beam
- X = distance from slab scatterer to dose point
- μ_1, μ_2 = linear adsorption coefficients for the incident and scattered radiation energies
- θ_1, θ_2 = the incident and emergent angles made with the normal to the scattering slab
- $\frac{d\sigma}{d\Omega}$ = Klein-Nishina cross section for the scattering angle $\theta_1 + \theta_2$.

* Stephenson, Introduction to Nuclear Engineering, 1954, p 197

Using the geometries of source, dose point, and scatterer which give the highest dose and therefore the most conservative results, yields a dose of 20 mr/hr from the three modes of radiation reaching a man in the main bay. However, the worst geometries for each radiation path cannot occur simultaneously. This, combined with the inherent conservatism in the calculations leads to an expected dose of from 1 to 10 mr/hr to a man in the main bay, from a core in the balcony, or conversely a dose of from 1 to 10 mr/hr in the balcony from a core in the main bay.

WINDOWS

The design of two 6 ft shielding windows and one 5 ft shielding window for the main bay of the E-MAD building is shown on Drawing 1425-L-13. The two 6 ft windows, while they have a different periphery, have the same axial configuration of the shielding materials. The three types of window use the same combination of shielding glasses separated by mineral oil. However, the oil thickness in the 5 ft window is 1 ft less than that in the 6 ft windows.

The 6 ft windows are designed to shield a Phoebus core, 24 hr after shutdown. For design purposes, it is centered in front of the window with the core surface at a distance of 4 ft from the inside wall of the building. Both 6 ft windows give identical dose rate profiles from the hot to the cold side.

The 5 ft type of window is designed to shield a Phoebus core-engine combination, 24 hr after shutdown. In its design position, the core is centered in front of the window with its surface at a distance of 5 ft from the inside wall of the building. The engine surrounds the core and thus acts as an additional shield.

Shielding calculations have been made for the 5 ft and 6 ft windows. The dose rate has been determined for each interface in the windows to determine to what radiation level each of the shielding glasses and each of the layers of mineral oil would be subjected in actual operation. In the dose rate calculation, the actual cylindrical configuration of the Phoebus core has been used, taking into account its self-shielding characteristics. The

shielding effect of the engine was discounted by applying an attenuation factor of 2.9 to the dose rate which would prevail on the hot side of the 5 ft window if the core were bare.

In presenting the dose rate profile through each window, each interface is identified by a location number. These location numbers run from 1 to 12, starting on the hot side (See Fig. 20). The location numbers define the boundaries of the following shielding materials:

<u>Boundaries</u>	<u>Material</u>	<u>Density</u>	<u>Thickness (in.)</u>
1 - 2	Plate Glass	2.7	1
2 - 3	Mineral Oil	0.875	*
3 - 4	Non-Browning Glass	3.3	7-1/2
4 - 5	Mineral Oil	0.875	*
5 - 6	Hi-D Lead Glass	6.2	5
6 - 7	Mineral Oil	0.875	*
7 - 8	Hi-D Lead Glass	6.2	5-1/2
8 - 9	Mineral Oil	0.875	*
9 - 10	Hi-D Lead Glass	6.2	5-1/2
10 - 11	Mineral Oil	0.875	*
11 - 12	Plate Glass	2.5	1

*The thicknesses of the oil layers can be scaled off from Drawing 1425-L-13. The dose rate profile for the 5 ft window is presented in Fig. 21, which indicates that the dose rate on the cold side is 1.05 mr/hr. For the 6 ft windows, the dose rate profile is shown in Fig. 22, which indicates that the dose rate on the cold side is 0.96 mr/hr. These dose rates indicate that the total integrated dose through the window for one week will be substantially less than 100 mr/wk.

The windows are designed for a dose rate of 1 mr/hr in order to provide an extra safety factor in the operation of the facility. Although the 5 ft wall allows higher dose rates through it than does the window, if any window becomes particularly important in the operation of the facility (because each fresh core is placed before the same window when the final operating sequence is determined for Phoebus), local shielding may be placed around the window to reduce the dose to an operator to 2.5 mr/hr. The dose rates at other windows or positions in the galleries will be correspondingly low because of distance attenuation from the engine.

FIG. 20 LOCATION NUMBERS FOR 5 FT AND 6 FT SHIELDING WINDOWS
(See Drawing 1425-L-13 for location of windows)

FIG. 21 DOSE RATE THROUGH 5 FT SHIELDING WINDOW

FIG. 22 DOSE RATE THROUGH 6 FT SHIELDING WINDOW

If the oil should leak from the window, or be deliberately drained in order to change oil, the dose rate on the cold side of the windows would be 16 mr/hr. This would permit a man to work at the window for 6 hr, even if a fresh bare core were directly in front of the window, 10 ft from the man.

Steel Collars for Shielding Windows

An analysis has been made to determine the additional steel shielding necessary for the shielding windows in Locations E-7, E-9, N-1, N-2, S-1, S-2, S-4, S-8, S-9, S-10, W-6, W-7, W-9 and W-15. These windows, shown on Drawing 1425-L-13, are designed for a 6 ft wall. The hot side of each window contains a pool of mineral oil and is flared for ease of viewing. The remainder of the window contains slabs of shielding glass separated by mineral oil. The entire window is held in a steel casing. Figure 23 presents a schematic representation of the window.

If a Phoebus core, 24 hr after shutdown, were placed in line with gamma path 1-2 (see Fig. 23), a dose rate of 15.67 mr/hr would prevail at location 1. This is above the tolerance level of 2.5 mr/hr and would result because the direct path 1-2 would bypass the heavy shielding glass and pass through a thick layer of oil rather than through an all concrete thickness. In order to reduce the dose level at location 1 to 2.5 mr/hr, a total steel thickness of 7-1/4 in. must be inserted in path 1-2. The length of path 1-2 intercepted by the window casing steel forms a portion of this required 7-1/4 in. The portion of path 1-2 intercepted by the window casing is approximately 3-1/2 in. (see Drawing 1425-L-13). Thus an additional thickness of 3-3/4 in. of steel must be inserted in path 1-2. This could be in the form of a collar of steel plate, 3-3/4 in. thick. It would be fastened to the window casing and would extend sideways parallel to the wall faces, its lateral extension depending on its position along the axis of the window. An analysis of a number of gamma ray paths indicates that the most effective location is at the junction of the conical sections holding the oil and the shielding glasses, with the "hot" side of the collar in the junction plane. In this position the collar needs to extend only as far as the oil pool at its widest point. The steel collar, as recommended, is shown in Figure 23.

FIG. 23 STEEL COLLAR DESIGN FOR SHIELDING WINDOW

Oil Lifetime in the Windows

In order to avoid the exposure of thick slabs of shielding glass to fields of high gamma intensity, the shielding windows are designed with a pool of oil on the hot side. Only a cover glass, 1 in. thick, separates the oil and the source of radiation.

In such a shielding window the oil normally has a limited life before it discolors due to the high gamma flux. In order to determine the integrated dose to the oil it is necessary to know the average gamma flux in the oil.

Straightforward shielding calculations readily give the dose rate through the oil.

In order to find the numerical value of this average dose rate a generalized formula has been derived for the following conditions:

1. The oil pool has the form of a prismoid whose end faces are rectangles.
2. The direction of the impinging gamma radiation from the source is perpendicular to the end faces of the oil pool.
3. In a plane passing through the oil pool in a direction parallel to the end faces the gamma dose rate is uniform.
4. Uniform mixing of the oil is assumed to take place over an interval of several days.

A plan view of the oil pool is as follows:

Assume:

an r-coordinate axis perpendicular to the end faces of the oil pool
in the direction of the impinging gamma radiation,

and:

r_1 = coordinate of the hot face

r_2 = coordinate of the warm face

D = gamma dose rate corresponding to any coordinate r in the
oil pool.

The volumetric average dose rate is:

$$D_{Ave} = \frac{1}{V} \left[e^{ar_2} \left(\frac{E + FR + GR^2}{a} - \frac{F + GR}{a^2} + \frac{2G}{a^3} \right) - e^{ar_1} \left(\frac{E}{a} - \frac{F}{a^2} + \frac{2G}{a^3} \right) \right]$$

Nomenclature:*

$$a = [\ln D_2 - \ln D_1] / R$$

b_1 = horizontal width of hot face of oil pool, cm

b_2 = horizontal width of warm face of oil pool, cm

e = base of natural logarithms (2.7183)

h_1 = height of hot face of oil pool, cm

r_1 = r-coordinate of hot face of oil pool, cm

r_2 = r-coordinate of warm face of oil pool, cm

$$A = b_1 h_1$$

$$B = [b_1 (h_1 - h_2) + h_1 (b_1 - b_2)] / (r_1 - r_2)$$

$$C = [(b_1 - b_2) (h_1 - h_2)] / (r_1 - r_2)^2$$

D = dose rate corresponding to coordinate r , r/hr

* Units must be consistent; units listed here are illustrative only.

D_1 = dose rate at hot face of oil pool, r/hr

D_2 = dose rate at various faces of oil pool, r/hr

$$E = \left[AD_1 \frac{r_2}{r_2 - r_1} \right] \left[D_2 \frac{r_1}{r_1 - r_2} \right]$$

$$F = \left[BD_1 \frac{r_2}{r_2 - r_1} \right] \left[D_2 \frac{r_1}{r_1 - r_2} \right]$$

$$G = \left[CD_1 \frac{r_2}{r_2 - r_1} \right] \left[D_2 \frac{r_1}{r_1 - r_2} \right]$$

R = distance between end faces of oil pool ($= r_2 - r_1$), cm.

V = volume of oil pool, cu cm

$$= A (r_2 - r_1) + 1/2 B (r_2 - r_1)^2 + 1/3 C (r_2 - r_1)^3$$

The following data for the oil pool in a 6 ft shielding window designed for the E-MAD project as shown on Drawing 1425-L-13, apply:

$$b_1 = 182.9 \text{ cm}$$

$$b_2 = 146.30 \text{ cm}$$

$$r_1 = 5.08 \text{ cm}$$

$$r_2 = 89.9 \text{ cm}$$

$$h_1 = 182.9 \text{ cm}$$

$$h_2 = 100.6 \text{ cm}$$

$$D_1 = 6.67 \times 10^5 \text{ r/hr}$$

$$D_2 = 9.8 \times 10^3 \text{ r/hr}$$

Application of the equations presented above yield a volumetric average dose rate in the oil of 1.9×10^5 r/hr.

Mineral oil is assumed to brown at an integrated dose of 10^7 r. Therefore, if a fresh core 24 hr after shutdown is placed 4 ft from a 6 ft window, the minimum lifetime of the mineral oil is:

$$\frac{10^7}{1.9 \times 10^5} = 53 \text{ hr}$$

Although the conditions set forth are the worst possible ones, it is seen that this lifetime would be too short for practicality. However, there are ameliorating factors, such as the fact that the core will be a large distance from most of the windows most of the time. Actually, mineral oil may prove to be satisfactory with integrated doses higher than 10^7 r.

Therefore, to hold down the cost of the windows initially, mineral oil has been specified for the windows. In addition, inlets and outlets are provided for the oil chamber so that the oil may be readily changed. In the event that certain windows are subject to sufficiently high doses in actual practice for mineral oil to prove inadequate from a radiation damage standpoint, oils such as Adakane* may be used.

Although definitive specifications are not available for this oil, the lifetime of Adakane has been established as 2×10^8 r. This oil, selling for about \$1/lb, is about 10 times as expensive as mineral oil. Alternate materials may also be used. Another solution is to periodically circulate the oil through an ion exchange resin to remove any discoloration. In oil refinery practice it is customary to remove coloring matter from lubricating oils or waxes by percolation through activated clay. The coloring matter, being polymeric in nature, is preferentially absorbed by the clay. It is reasonable to assume that activated clay will likewise remove polymers formed as a result of irradiation. It is thus quite possible that the life of mineral oil in a shielding window can be extended greatly by periodic circulation through a bed of activated clay. The provision of inlet and outlet valves for the oil allows any problems which may arise due to radiation damage to the oil to be solved in a manner best suited to the operating requirements of the facility.

A second potential problem is bubble formation in the window oil. In general, the deterioration of an organic substance under gamma radiation consists of polymerization with attendant evolution of light hydrogen-rich

*Archer-Daniels-Midland Company

decomposition products. The polymers contain less hydrogen per carbon atom than the original oil. The decomposition products therefore contain more hydrogen per carbon atom than the original oil. Under gamma radiation, the evolution of hydrogen and methane (CH_4) is therefore common. Bubble formation may begin in mineral oil at a dose rate of 10^5 r/hr. If a bare core, 24 hr after shutdown, were to be placed 4 ft from a window, the dose rate in the few inches of oil closest to the source would be approximately 5×10^5 r/hr. This would create a fair likelihood of significant bubble formation. It is possible but unlikely, that there would be bubble formation as a result of placing the engine at 5 ft from the window. Data on bubble formation is not sufficiently precise to predict this with a high degree of accuracy. With the engine at over 10 ft from a window bubble formation in the oil in that window is not expected to be a problem.

If this problem of bubble formation does develop in any window, special oils such as Adakane may be employed in the window wherein the problem develops. Long chain oils, such as Adakane, have higher thresholds for bubble formation.

DUCTS AND PENETRATIONS

There are a number of penetrations into the main bay for manipulator connections, heating and ventilating ducts and electrical wiring. Each of these penetrations has been designed to insure that there will be no radiation streaming problem associated with it. In the case of ducts too large to prevent streaming by appropriate shaping alone, additional shielding has been designed in order to eliminate any problem.

The design basis used is that: 1) the local dose rate increase to a man in the immediate path of a penetration through a 5 ft thick wall should not exceed 10% of the dose behind the solid 5 ft wall; 2) the local dose rate increase to a man in the immediate path of a penetration through a 6 ft wall should not exceed 20% of the dose in the absence of the penetration in the 6 ft wall; and 3) the local increase in dose levels due to penetrations does not represent a whole body dose. Care has been taken to insure that any reduction in shielding effectiveness due to a penetration will not cause a streaming path of radiation from 1 ft to 8 ft above floor level in the operating galleries.

Because of the large physical size of the source in the bay, a collimated penetration views only a small portion of the source. For example, a 4 in. pipe aimed directly at the core views $< 1\%$ of the source volume. Thus, if there is a 1 ft reduction in wall thickness along a portion of the path taken by a 4 in. pipe through the wall, the dose rate directly in front of the streaming path is increased by a factor of $< 20\%$, although the dose rate would be approximately 20 times greater if the entire wall were decreased by a thickness of 1 ft. The spacing of the penetrations has been arranged to minimize any additive effects.

In the design of the penetrations, reductions in wall thickness of up to 1 ft have been allowed along the path of penetrations 1 in. and under in diameter through the 6 ft wall, and reductions of wall thickness of up to 9 in. have been allowed along the path of penetrations over 1 in. in diameter and under 4 in. in diameter through the 5 ft wall. This is conservative because no credit has been taken in the calculations for the material or equipment which will usually fill the penetrations.

Electrical conduit boxes which recess more than 3 in. are to be backed up with steel to compensate for loss of concrete, unless the locations are > 8 ft high or < 1 ft above the operating gallery floor level. For example, recesses facing an operating gallery between 1 ft high and 8 ft high with a depth of 6 in. must be backed up with a 2 in. steel slab extending 1 in. beyond the width of the recess. Conduit Box X, adjacent to the windows, which is $22\text{-}1/2$ in. $\times$ $12\text{-}1/2$ in. $\times$ 6 in. must be backed by a steel plate $24\text{-}1/2$ in. $\times$ $14\text{-}1/2$ in. $\times$ 2 in.

The basic penetration types which have been used are the single offset, the double offset, the looped or curved penetration, and those where the exact position and shape of the penetration meets shielding requirements by their physical location.

In the case of penetrations over 1 in. in diameter with a single or double offset, shown schematically in Fig. 24, the penetration runs from the outlet into the wall at an angle with a normal such that the relationship between the length L of any straight section through the wall of thickness t and the angle θ it makes with the normal to the wall is $L = 9 \text{ in.} + t (\sec \theta - 1)$ through the 5 ft wall where the streaming path would be directed towards a man in the operating gallery. This is derived as follows.

The concrete thickness along the path of a penetration through a wall should be the full thickness of the wall t , less the permissible open path P .

FIG. 24 TYPICAL PENETRATIONS THROUGH SHIELD WALLS

The slant thickness of the wall along the path of the penetration is $t \sec \theta$ where θ is the angle with the normal to the wall, and the length of the open portion of this penetration along a straight line is L .

Thus, $t \sec \theta - L = t - P$ or $L = t (\sec \theta - 1) + P$. If a 3 in. penetration with a single offset is considered as shown in Figure 24, the minimum angle θ which will satisfy the equation for a 5 ft wall is 70° . If the penetration is 1 in. or less then the permissible void normal to the wall is 18 in. and the penetration may have an angle $\theta = 31^\circ$. These are minimum angles; greater angles than those specified are also acceptable. To find the required angle for a single offset, knowing the acceptable penetration length normal to the wall, the following relationship may be used:

$$\cos \theta = \frac{2P}{t-P}$$

where:

P = the acceptable penetration length normal to the wall.

In cases where the permissible minimum angle and the physical relationship between the receptacle boxes does not permit the use of a single offset, multiple offsets may be used, as shown in Figure 24.

If the penetration must have a portion of its length running normal to the wall face, this length may not exceed 1 ft for 1 in. to 4 in. pipe through the 6 ft wall, or exceed 9 in. for 1 in. to 4 in. pipe through the 5 ft wall. These dimensions include any loss of wall thickness due to a recessed electrical conduit box which is in line with the pipe.

A summary of the design criteria for piping and conduit penetrations is shown in Table 5 on the following page.

The penetrations which are specifically detailed include all of the heating and ventilating ducts, and the larger penetrations in the vicinity of the windows and other special conduits and pipes.

Instrumentation Penetrations

Penetration for pressure and temperature detector tubes through the main bay walls and the maintenance balcony walls have been designed with offsets to prevent the above indicated radiation streaming. In some cases lead plugs are provided at the cold face of the wall to reduce the scattered dose rate to levels equal to or below that of the direct

TABLE 5 - PIPING AND CONDUIT PENETRATIONS

<u>Concrete Wall Thickness</u>	<u>Penetration Diameter</u>	<u>Maximum length straight penetration pointing towards area in gallery from 1 ft to 8 ft high</u>	<u>Typical minimum angle θ for a single Offset Penetration</u>
5 ft	0 to 1 in.	$L = 18 \text{ in.} + t (\sec \theta - 1)$	31°
5 ft	Over 1 in. to 4 in.	$L = 9 \text{ in.} + t (\sec \theta - 1)$	70°
6 ft	0 to 1 in.	$L = 21 \text{ in.} + t (\sec \theta - 1)$	35°
6 ft	Over 1 in. to 4 in.	$L = 12 \text{ in.} + t (\sec \theta - 1)$	67°

t = thickness of concrete wall

θ = angle between penetration section of length L and normal to the wall

radiation through wall where straight penetrations are required. Where possible the penetrations are pointed in a direction such that the core or engine could not be placed in line with them, and long straight sections are not in line with any possible source, or are pointed toward an outside area well above a man's head, away from the critical operating gallery area.

In one section of the north wall, where a number of 4 in. and 6 in. tubes for ground service equipment instrumentation leads pass into the main bay between a pilaster and the filter bank structure, an extra concrete thickness of 18 in. is to be provided to a height of 10 ft to compensate for the additive effect of multiple penetrations.

The piping drains underneath the first floor of the hot disassembly bay, consisting of two 6 in. and one 4 in. pipe near the west wall, and one 4 in. pipe near the east wall, are 3 ft below the floor level and present no problem. Similarly, the penetrations under the core and engine disassembly cells are below the floor level and present no problem.

Mechanical Penetrations

Straight-through penetrations are provided above the windows for master-slave manipulators. Lead shielding is specified to fit into the mechanical penetrations to attenuate radiation which may otherwise stream through the straight penetrations. These lead plugs are 9 in. long.

Air Ducts

The air ducts require large penetrations. The shielding of these ducts is discussed below.

Main Exhaust Duct

This duct consists of a large penetration in the north wall of the main bay. The air passageway goes through a set of filters, then goes beneath the north wall in a U turn and passes into a shielded radiation trap between the main bay and the stack (see Fig. 25). The depth of penetration of the duct beneath the north wall of the main bay is designed to insure that radiation cannot escape through the duct without four successive scatters. In addition, the first 9 ft 6 in. of the connection from the filter bank to the stack blowers is shielded with a 2 ft thickness of concrete to attenuate the scattered gammas to tolerance levels.

Main Air Intakes

The air intakes for the main disassembly bay are located on the roof. In order to prevent large openings which could significantly affect the scattered dose rate to the ground or upper galleries, shielded covers in the form of concrete boxes are provided, designed to attenuate the radiation passing through these ducts. The concrete at the top of these concrete boxes is 36 in. thick and the side walls of these boxes are 18 in. thick. The opening for incoming air points to the west, away from the cell bay. This reduces the dose rate that streams through the ducts to negligible levels in the areas of concern.

Balcony Air Ducts

The air transfer passageway between the crane maintenance balcony and the hot disassembly bay is a large duct which penetrates the wall between the balcony and hot disassembly bay. In order to prevent streaming through this duct, two 8 in. thick steel plates are placed in the streaming path to attenuate the radiation.

FIG. 25 MAIN EXHAUST DUCT SHIELDING

MAIN BAY FUEL MODULE STORAGE PIT

A pit is provided in the floor of the main bay for the temporary storage of spent fuel modules. Up to 5/6 of a core may be stored in this area. This pit is 16 ft-6 in. deep, and is provided with a stepped concrete cover 5 ft thick. Due to the manner in which the modules are spaced to eliminate the possibility of criticality, the dose rate on the upper surface of the pit cover would be <25 mr/hr assuming the modules came from a fresh core 24 hr after shutdown. However, it is not anticipated that fuel modules could be stored in this pit earlier than two days after reactor shutdown. Therefore, the dose rate on the upper surface of the cover is expected to be <10 mr/hr. The inside of the main bay is a limited access area in which a dose rate of 25 mr/hr is permitted.

RADIATION DAMAGE

Radiation damage to materials in the Main Disassembly Bay, Crane Maintenance Balcony and Core and Engine Disassembly Cells is a potential problem. Dose rates in these areas, from a fresh core or engine, exceed 10^5 r/hr. Integrated doses are dependent upon the location of the source and the time of exposure of specific equipment. This is an unknown factor at the present time. However, an integrated dose of 1.75×10^9 r has been specified for some equipment such as the wall mounted manipulators. This integrated dose is based upon a 10 year service life, one fresh engine/week, and the engine 10 ft from the manipulator for 1/4 of each 24 hr day.

Materials particularly affected by radiation damage include organics and silicones, particularly oils, elastomers, plastics and glass. The most important organic material is the oil used in the windows. Radiation damage to oil and glass has been discussed in the window section of this report. Radiation damage to organic coatings has been considered, and radiation-resistant paints have been specified for the inside surfaces of the areas cited above. These paints may be chosen from coatings based upon phenolic, furane, alkyd, silicone-alkyd, neoprene, styrene-butadiene or epoxy formulations, and should have a smooth washable surface.

Electrical insulation, and elastomers such as those used for manipulator boots should also have high radiation resistance. The most highly resistant materials, consistent with their cost and function should be used. Table 6 lists threshold doses for radiation damage, and doses required to produce 25% damage for elastomers and plastics.

TABLE 6 THRESHOLD AND 25% DAMAGE DOSAGES
FOR ELASTOMERS AND PLASTICS*

<u>Material</u>	<u>Roentgens of Gamma Photons</u>	
	<u>Threshold</u>	<u>25% Damage</u>
ELASTOMERS**		
Natural Rubber	2.1×10^6	2.6×10^7
Butyl Rubber	2.1×10^6	4.1×10^6
Buna-S	2.1×10^6	1.1×10^7
Hycar OR	2.2×10^6	7.5×10^6
Neoprene	2.2×10^6	6.1×10^6
Hycar PA	1.1×10^6	3.6×10^6
Thiokol ST	5.7×10^5	1.7×10^6
Silicone Rubber SE 550	9.8×10^5	6.0×10^6
Silicone Rubber SE 550	9.8×10^5	8.2×10^6
Silicone Rubber SE 551	9.8×10^5	1.1×10^7
Silicone Rubber SE 371	9.8×10^5	1.3×10^7
Silicone Rubber SE 750	9.8×10^5	1.3×10^7
Silicone Rubber Silastic 7-170	1.4×10^6	4.6×10^6
PLASTICS***		
Nylon (FM 10001, FM-1, FM 3003)	9.2×10^5	5.0×10^6
Polyethylene (Polythene)	2.0×10^7	9.6×10^7
Teflon	2.0×10^4	4.5×10^4
PVC (Geon 2046)	2.2×10^7	1.3×10^8
Polyvinyl Formal (Formvar)	1.7×10^7	8.9×10^7
Mylar	3.4×10^7	1.4×10^8

* Collins, C. G. and Calkins, V. P., "Radiation Damage to Elastomers, Organic Liquids and Plastics." APEX-261, September, 1956, General Electric Company, Aircraft Nuclear Propulsion Department.

** Irradiation Temperature - 70°F.

*** Irradiation Temperature - 75-105°F., irradiation at higher temperatures will accelerate deterioration.

NUCLEAR HEAT LOAD TO FACILITY

The heat output from a Phoebus core 24 hr after shutdown has been calculated to be 80 kw, based upon data received from Aerojet General Corporation. This rate of heat output falls off with time in accordance with the curve shown in Fig. 26.

The heating and ventilating systems for the main bay have been designed to handle one fresh core releasing 80 kw of heat plus one old core releasing 10 kw in the main bay plus the heat release due to equipment and lighting while there is one old core releasing 10 kw in the balcony.

The H and V system for the crane maintenance balcony and the core disassembly cells has been designed to handle one fresh core in any one place plus the heat release due to lighting and equipment, and the heat release from old cores in each of the remaining areas.

FIG. 26 DECAY HEAT AFTER SHUTDOWN

STACK HEIGHT ANALYSIS

The purpose of the stack is to insure that any airborne fission products released in the main bay do not exceed the maximum permissible requirements for air contamination at ground level or at the E-MAD air intake. The assumed maximum fission product contamination in the main bay is based upon the maximum concentration value of 250 MPC as observed by LASL in the R-MAD hot bay.

The effluent from the stack will be well under the maximum permissible concentration because of the presence of an exhaust filter with an efficiency of 99.97 (D.O.P. Test). If the filter should fail in whole or in part, a monitor in the stack will detect this condition so that it may be corrected.

There is also an intake filter, having a 90% efficiency (NBS Test), for the air that goes to the operating galleries. This filter affords protection from possible airborne contamination from tests in the area or from activity released elsewhere at the National Nuclear Rocket Development Site.

Despite the presence of these filters, the stack height has been designed on the basis of a gaseous effluent from the stack with a concentration of 250 MPC. The design stack height is 115 ft above grade. Therefore, the half height of the plume, based on a 0.1 centerline plume concentration, will not intersect the highest point on the E-MAD facility, i.e., the top of the cooling tower.

The required stack height is one which assumes a dilution factor from the stack to the ground sufficient to give a ground concentration ≤ 1 MPC when the gaseous effluent from the stack is at a concentration of 250 MPC. Also, the stack must be high enough so that the plume does not intersect the air intake duct on the roof of the E-MAD building, or any other structural obstruction. The highest obstruction is the cooling tower. To meet this latter requirement a stack height of 115 ft above grade is required. This height is arrived at as follows:

Top of cooling tower	=	98 ft above grade
Distance of cooling tower from stack	=	170 ft
Half-height of plume at 170 ft from stack	=	23 ft
Increase in effective stack height, due to exhaust velocity	=	6 ft
Exhaust temperature from main bay with source present	=	105 ft

Therefore, stack height = $98 + 23 - 6 = 115$ ft

The equation for the half height of the plume is:

$$Z_0 = \left[\frac{4 \ln 10 K_z x}{\bar{\mu}} \right]^{1/2*}$$

where $K_z = 5 \times 10^3$ sq cm/sec

$x = 170$ ft (= distance to cooling tower)

$\bar{\mu} = 5$ m/sec**

Therefore: $Z_0 = 23$ ft

Since the plume does not intersect the cooling tower which is 15 ft higher than the air intake on top of the main bay, none of the plume reenters the ventilation system of the building.

Normally the air temperature in the main bay will be maintained at 105 °F or less by the air conditioning system. However, when personnel access is required (no source present in bay), the bay must be maintained at lower temperatures than 105 °F.

The air intake on top of the main bay is provided with a 90% efficiency filter. However, since the intake is located 15 ft lower than the cooling tower, the exhaust plume will not intersect this intake duct under normal atmospheric conditions.

*From Sutton, "Micrometeorology," McGraw-Hill, 1953

**5 m/sec assumed because K_z from Sutton was based on experimental data for this wind velocity (See Sutton, p. 279). For other calculations $\bar{\mu} = 3$ m/sec was used.

The fraction of MPC on the ground is calculated below for a complete failure of the exhaust filter.

For a ventilation rate of 20,000 cfm, a wind velocity of 3 m/sec, and a stack height of 115 ft, the dilution factor from the stack to the ground is 1800. This is calculated starting with the following equation:

$$x = \frac{2Q}{\pi e \bar{\mu} h^2}$$

where: Q = emission rate from stack, curies/sec

$\bar{\mu}$ = wind velocity, m/sec (= 4 m/sec)

h = stack height, m

and $Q = \frac{v}{60} \times C_o \times 2.83 \times 10^4$ cu m/cu ft

where v = ventilation rate, cfm (= 20,000 cfm)

C_o = concentration in bay, curies/cu cm

Since the maximum anticipated concentration is 250 MPC,

$$\frac{\text{concentration at stack}}{\text{permissible concentration on ground}} = \frac{C_o}{x} = 250$$

and from the earlier equations

$$\frac{\text{concentration at stack}}{\text{actual concentration on ground}} = 1800$$

Therefore, the maximum anticipated concentration on the ground, upon failure of the filter and assuming a concentration in the main bay of 250 MPC, is approximately 14% of the MPC.

RADIATION MONITORING

The philosophy used in radiation monitoring the E-MAD Facility is to provide an adequate, integrated surveillance of the facility. The installed radiation monitoring for this building may be divided into three systems (see Drawing 1425-Y-10):

1. Neutron Monitoring System
2. Gamma Monitoring System for Process Areas
3. Gamma Monitoring System for Personnel Areas
Adjacent to the Process Areas

Each core has a neutron monitor, which travels with the core as it moves about the facility. Remote record and alarm of the neutron count rate are provided. Fixed gamma detectors with remote readout are located in the process areas (main disassembly bay, crane maintenance balcony, hold tunnel, core disassembly cell and engine disassembly cell). Personnel areas adjacent to these process areas are provided with local gamma indication and alarm with individual remote alarm to indicate the trouble area to the health physics personnel. Portable gamma monitors are used to supplement the installed monitoring. Hand and foot counters are located at the personnel entrances to the process areas.

The health physics office is the center of all radiation monitoring operations for the E-MAD facility. During initial operations, this office has been temporarily located on the first floor of the east operating gallery, adjacent to the engine disassembly cell. In the final facility it is relocated in the office area of the building. Instrument local panel Y1 is installed here. This panel contains the readout instrumentation for the neutron and gamma radiation monitoring systems, which consist of a 40-point annunciator assembly, a 20-channel gamma radiation recorder, the amplifiers for the process area detectors, two neutron recorders, and the patch panel for the neutron monitor connection boxes. Provision has been made for future monitoring instrumentation which will be required for Phase II. Power for the instruments on this panel is supplied from the emergency lighting panel EM-2. A buzzer cutout switch is provided so that the annunciator's audible alarm can be silenced for the engine approach operations.

During operations involving the approach of a radioactive engine to the E-MAD building, the health physics office, like other unsheltered areas of the facility, becomes temporarily unusable. Certain health physics personnel remain on duty in the master control room (MCR), while the remainder go to the shelter areas. Signals from the process area gamma monitors are recorded in the MCR for this purpose. This record also supplies the MCR operators with the radiation intensities in these areas for use in conjunction with the operation of the equipment and personnel access doors.

The neutron monitoring system consists of a network of circuits from panel Y1 to connection boxes located throughout the process areas, wherein materials which represent a potential criticality hazard can be handled. The neutron monitor is plugged into this connection box, which contains signal and 120 v ac power receptacles. Power supply is from emergency lighting panel EM-1 or EM-2. This signal circuit is connected to one of the two neutron count rate recorders on panel Y1 through the neutron monitor connection box patch panel. This patching is shifted as a given core is moved about the building, and the associated neutron monitor is connected to another connection box. Neutron monitor connection boxes are located as follows:

<u>Location</u>	<u>Quantity</u>
Core Storage Area	2
Main Assembly Area	2
Main Disassembly Bay	2
Crane Maintenance Balcony	2
Core Disassembly Cell	1
Hold Tunnel	1
Engine Disassembly Cell	1

Alarms from these recorders are provided on panel Y1 to annunciate a high neutron count rate.

The gamma monitoring system for the process areas consists of a detector permanently mounted in the process area and connected by special cable to individual amplifiers on panel Y1. Each amplifier indicates the radiation intensity of the area monitored. Instrument range is 0.01 to

to 10,000 mr/hr. In addition, a high radiation alarm switch is provided. This permits individual settings of each alarm point. An alarm is provided on panel Y1 to annunciate this high radiation signal from any amplifier. A light on each amplifier indicates the annunciated channel. The outputs of these amplifiers are recorded on both panel Y1 and in the MCR. These radiation detectors are located in the following areas:

Core Storage Area

Main Assembly Area

Main Disassembly Bay Over the Personnel Door

Main Disassembly Bay Over the Fuel Module Storage Pit

Main Disassembly Bay Behind the Exhaust Plenum Filter

Main Disassembly Bay Roof

Crane Maintenance Balcony Over the Personnel Door

Core Disassembly Cell

Hold Tunnel

Engine Disassembly Cell

Radioactive Waste Hold-up Tank Pit

Stack No. 1

Stack No. 2

The roof detector serves to monitor the radioactivity during an engine approach, the gamma dose rate on the roof, and any radioactivity in the stack effluents which may blow towards the building.

The gamma monitoring system for the personnel areas adjacent to the process area consists of local monitor units having radiation and intensity indication and an alarm annunciation on the monitors. In addition a remote alarm indication is provided on panel Y1 for each monitor to target the location of the alarm in the health physics office. These monitors are portable, but captive at the end of a 50-ft cable reel. These monitor units are located in the galleries at intervals which permit monitoring the entire shield wall in the galleries. This reel supplies the 120 v ac power from either emergency lighting panel EM-1 or EM-2, as well as the remote alarm signal circuit. These monitor units are located as follows:

<u>Location</u>	<u>Quantity</u>
First Floor Operating Galleries	6
Second Floor Operating Galleries	6
Third Floor Operating Galleries	3

All equipment and personnel access doors in the process area, are controlled from the Master Control Room. Local operation of any of these doors from the outside is possible only with MCR permission. In addition, when operation is local for either of the personnel access doors, entry into the process area is possible only with a key, which is in the possession of the health physics personnel. Each personnel access door assembly pair consists of two shielding doors, interlocked so that only one can be open at any one time. Operation of the personnel access door from within the process area is possible at any time to permit emergency egress of personnel.

TESTING AND CHECKOUT OF SHIELDING WALLS

The following is an outline of the testing and checkout procedure proposed for the shielding walls of the E-MAD Building. Enough data are included to arrive at an approximate time and cost estimate of the checkout procedure.

It is suggested that the shielding walls of the E-MAD facility be tested in two stages. In the first stage, a 10 C gamma source would be used. The second stage would require a 10,000 C source. The reason for testing in two stages is the following. A minimum source strength of the order of 10,000 C is required to test the 6 ft thick concrete walls of the main bay for shielding integrity in order to give practical count rates. Using a sensitive scintillation counter with a large (3 in. x 3 in.) sodium iodide crystal, count rates of the order of 4 counts per second can be obtained. This presumes that the source is right up against the inside of the wall and the detector right up against the outside of the wall. The count rate is based upon the 1.6 mev gamma from a barium-lanthanum source. However, it is dangerous to use a 10,000 C source unless the shielding walls have first been checked for gross defects. There have been instances where underneath shielding windows the concrete poured from both sides of the window had not been driven home against the bottom of the window liner and a veritable hole existed underneath the window. Using a 10,000 C source under these conditions may easily lead to serious overexposure of the operator.

Such serious flaws in the concrete are especially apt to occur underneath penetrations and in places where there is an accumulation of reinforcing steel. It is therefore suggested to specially test those areas where such impediments to the flow of concrete exist and to do this with a relatively weak source and a direct reading instrument prior to the final testing. By using a 10 C source and a direct reading instrument the operator would be in a good position to avoid overexposure, even if a hole clear through the concrete exists between the source and the operator. The direct reading instrument would give him immediate warning so he could step aside. Such a direct reading instrument (portable survey meter) is Jordan Model AGB-10-SR, having two ranges: from 0.01 to 10 mr/hr and from 10 mr/hr to 10 r/hr.

The 10 C source could be a standard piece of radiographic equipment complete with shielded carrier, source tube, exposure control cable and source position indicator. For testing around windows, the source tube can be strung around one side of the window at a time and the source moved slowly through the tube from one end of the window to the other. The survey meter would then follow the movement of the source. For cylindrical penetrations, such as sleeves or pipes, the source tube can be wrapped around the sleeve or pipe. As the source is moved around the penetration, the survey meter would continuously scan the perimeter of the penetration. A normal source tube length is 25 ft; a normal source is Co^{60} . A complete package, including a 10 C Co^{60} source, is the Multitron Model 110, available from Budd Company Instruments Division, Phoenixville, Pennsylvania.

While the operator puts the source tube in place, the source would, of course, be retracted inside the shielded carrier. During the testing, the source operator would be at the end of the 25 ft long control cable and normally some 40-50 ft away from the source. Even at this distance, he should stay as much as possible behind some form of portable shielding because the source, when in the source tube, is virtually unshielded.

Even though the above preliminary test procedure would readily spot gross defects in the shielding walls, the method is not sensitive enough to detect lesser flaws. These lesser flaws, however, may well give rise to dose levels above tolerance when a Phoebus core is inside the building. To ascertain whether the walls meet design conditions from the shielding standpoint, a stronger source and a more sensitive detecting instrument must be used.

For the final testing it is recommended to use a 10,000 curie source in conjunction with a scintillation counter using a 3 in. x 3 in. sodium iodide crystal. The scintillation counter would be of the single channel type, permitting "tuning" to any desired gamma energy. If a 10,000 C barium-lanthanum source is used, the instrument would be tuned to its 1.6 mev gammas. This tuning to a single frequency would have the advantage of almost completely eliminating all background radiation and thus giving reliable readings at much lower levels. At the same time all scattered radiation from the source would be eliminated because any scattered radiation would be degraded from the original 1.6 mev. Elimination of the effect of scattered radiation means that the readings would not be affected by the configuration of neighboring masses of

shielding material. The instrument recommended is supplied by Technical Measurement Corporation, 441 Washington Avenue, North Haven, Connecticut. It consists of the following components:

One Model SG3A2 Decade Scaler with Timer

One Model PA2A Linear Amplifier - Pulse Height Analyzer

One Model HV4A 1600 v Photo Multiplier Power Supply

One Harshaw Chemical Type 12S12/3 Integral Line Scintillation Detector with 3" x 3" Thallium Activated Sodium Iodide Crystal

The matter of supplying a 10,000 C barium-lanthanum source was discussed with Mr. John W. Schulte, CMB Development Office, Gamma Survey Group, L.A.S.L., Los Alamos, N.M. during a telephone conversation on June 4, 1962. Mr. Schulte informed us that he could make up barium-lanthanum sources up to 20,000 C and that these sources were obtained from spent MTR fuel elements. He stated that 10,000 C correspond to 10-12 grams of material.

The source configuration is dependent upon the following considerations. For testing a 6 ft thick concrete wall a 10,000 C source would give a direct dose level of only about 0.001 mr/hr on the cold side of the wall. The source and the detector should therefore be placed as close together as possible so as to keep distance attenuation to a minimum. This means that the source should be placed against the wall. Another reason for placing the source against the wall is that the position of the source can then be marked by means of a system of horizontal and vertical coordinates laid out on the wall. Knowing the exact location of the source on the inside of the wall is necessary because the detector should be placed exactly opposite the source on the outside of the wall. Granted that the source should be placed against the wall, only that portion of the wall covered by the source can be tested at any one time. This means that a source of small dimensions would lead to an inordinately long checkout time of the building, considering that approximately 50 - 100,000 sq ft of wall area must be checked. The use of a physically small source is thus not practical.

It is therefore suggested to divide the wall in modular areas of approximately 30 in. x 30 in. and to use a plane source exactly the size of this module. The modules on the walls could be marked and numbered. The numbers of corresponding modules on the inside and outside of the wall should be the same. Module numbers on the inside wall during the checkout procedure could be observed through the shielding windows in

the opposite wall. The plane source, which need not be in its carrier during the testing, could be hung from the crane hoist and be positioned over each module in turn. The detector would be located in front of the same module on the outside of the wall. With the source in place the module would then be scanned by the detector in a definite pattern in a definite time. This could be approximately 1 min/30 in. x 30 in. module. Assume that the number of counts collected in this manner is 240/module for a sound 6 ft wall. Therefore, a module with a flaw in it would give a higher count, perhaps 480. This would mean that if the wall has been designed for an operating dose rate of 2.5 mr/hr, this particular module would give a dose rate of the order of 5 mr/hr. Using a 1 minute scanning time and a 1 minute positioning time per module, the time required for testing the wall would then be 2 min/6.25 sq ft. The total testing time for the whole wall area would then be of the order of 200 hr. The use of multiple instruments would reduce this time proportionately. For a single instrument about 4 operators would be necessary, one for the counter, one for the detector, one for the source, and one for the relief of the others.

A plane source can be made up as a series of parallel tubes fastened together by chain links. As such, it acts like a curtain and could be rolled up for storage. A 10,000 C source could be made up of approximately 10 tubes, each holding 1000 C. By disconnecting the links, any source < 10,000 C could be made up for testing thinner walls.

There remains the matter of physically positioning the detector. It is generally recommended to shield the detector with 1 in. of lead. This would require a counterweight for easy manipulation. The detector would thus normally hang from a pulley, with a counterweight equal to the weight of the detector. This may give no difficulty inside an operating gallery. However, some sections of the building walls to be tested are out in the open. In these locations, it would be necessary to make provision for a platform to be suspended from the roof by means of hoists, as used by painters for painting the sides of a building. The operator of the detector would then have to hoist himself up and down along the modules and likewise have the pulley for his detector suspended from the roof.

It is suggested that some judgment be used to determine which parts of the building walls really need testing and to omit from the testing program those parts wherein a flaw is unlikely or where a flaw would not be of much consequence. Walls bordering on operating galleries are of

prime importance in testing because here the operating personnel would be directly and continuously exposed to any increased radiation levels resulting from a flaw in the concrete. The same consideration may not hold for wall areas near the roof. Also, wall sections containing a minimum of penetrations and reinforcing steel are not apt to contain voids in the concrete.

There has been mention of measuring over-all dose rates, which include the scattering contribution. This can be done with the scintillation counter recommended. It not only can be tuned to a definite frequency but it can also read all gammas above a set frequency. By adjusting this set frequency to the limits of the desired energy groups and doing this with and without a source in the building, the effect of background can be subtracted for each energy group. Any counts above background and not including the 1.6 mev gammas are due to scattering from the source.

ENGINEERING
DRAWINGS

GLASS NO.	DENSITY	THICKNESS	HEIGHT	WIDTH	GLASS TYPE
1	2.5	1"	2'-10"	4'-2"	PLATE GLASS
2	6.2	5/8"	2'-5"	3'-8"	HI-D LEAD GLASS
3	6.2	5/8"	2'-6"	3'-9"	HI-D LEAD GLASS
4	6.2	5"	2'-7"	3'-10"	HI-D LEAD GLASS
5	3.3	7/8"	2'-8"	3'-11"	NON-BROWNING TEMPERED PLATE GLASS
6	2.7	1"	6'-2"	6'-2"	NON-BROWNING TEMPERED PLATE GLASS

RELATED DWGS
 1425-A-4 - 1ST FLOOR PLAN
 1425-A-6 - 2ND FLOOR PLAN
 1425-A-8 - 3RD FLOOR PLAN
 HOT DISASSEMBLY BAY

NOTE:
 1- WINDOWS SHALL BE FABRICATED IN ACCORDANCE WITH PROCUREMENT SPEC. 1425-PS-5 OF E-MAD FACILITY

GLASS NO.	DENSITY	THICKNESS	HEIGHT	WIDTH	GLASS TYPE
1	2.5	1"	2'-8"	3'-2"	PLATE GLASS
2	6.2	5/8"	2'-6"	2'-7 1/2"	HI-D LEAD GLASS
3	6.2	5/8"	2'-6"	2'-9 1/2"	HI-D LEAD GLASS
4	6.2	5"	2'-6"	2'-9 1/2"	HI-D LEAD GLASS
5	3.3	7/8"	2'-6"	2'-9 1/2"	NON-BROWNING TEMPERED PLATE GLASS
6	2.7	1"	3'-11"	4'-8"	NON-BROWNING TEMPERED PLATE GLASS

PACKAGE "G"	FUTURE CONSTRUCTION
WINDOW & LINER	WINDOW & LINER
	E-13, W-3, W-4, S-5, S-6, S-7, W-16

GLASS NO.	DENSITY	THICKNESS	HEIGHT	WIDTH	GLASS TYPE
1	2.5	1"	2'-10"	4'-2"	PLATE GLASS
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6	2.7	1"	5'-6"	5'-6"	NON-BROWNING TEMPERED PLATE GLASS

PACKAGE "G"	FUTURE CONSTRUCTION
WINDOW & LINER	WINDOW & LINER
	E-1, E-4, E-10, W-1 & W-3, E-2, E-3, E-5, E-11, E-12, E-14, W-2, W-10, W-11, W-12, W-17,

ISSUED FOR BIDS PACKAGE "G"		DATE: 8-6-62		APPROVED: R. BROOKSHIRE	
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ATOMIC ENERGY COMMISSION - NATIONAL AERONAUTICS AND SPACE ADMINISTRATION		VITRO ENGINEERING COMPANY - A DIVISION OF VITRO CORPORATION OF AMERICA		SNPO-C CLEVELAND, OHIO NEW YORK	
N.R.D.S. E-MAD FACILITY RADIATION SHIELDING WINDOWS					
NASA AC CONT. NO. SNPO-C-3					
DRAWN BY: E.D.		DATE: 8-6-62		APPROVED: R. BROOKSHIRE	
CHECKED: H.D.		DATE: 6-22-62		APPROVED: [Signature]	
APPROVED: [Signature]		DATE: 6-22-62		APPROVED: [Signature]	
APPROVED: [Signature]		DATE: 6-26-62		APPROVED: [Signature]	
APPROVED: [Signature]		DATE: 6-26-62		APPROVED: [Signature]	
SCALE: 1"=1'-0"				DRAWING NO. 1425-L-13