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September 10, 1953

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TASK III SHIELDING FOR PROJECT CG-551

INTRODUCTION

Neutron and gamma radiation is emitted by the PuF_4 powder processed in Task III. Significant neutron and gamma dose rates are obtained near the Task III hood with present 340 unit batch size[1]. After firing the powder, the neutrons essentially disappear and the gamma flux decreases appreciably[5]. Equipment being designed for RMA Task III under Project CG-551 will allow for an increase in batch size up to 1600 units of metal as PuF_4. These larger batch sizes will increase the dose rates in direct proportion to the batch size[1,2].

In view of Radiological Sciences' desired design standards[3] of 60 mrem/week in a constantly occupied operating position, a study of Task III dose rates to be expected and shielding required was indicated.

The first thing encountered in this study was that a cursory search of the literature revealed no experimental data on attenuation for neutrons with energies equal to those of PuF_4 neutrons in shielding materials of interest here. F. R. Jones reported attenuation coefficients of water and paraffin for Po Be and Po B neutrons[4]. In order to have experimental data upon which to base design calculations, the Radiation Monitoring Unit of 234-5 Bldg. was requested to obtain neutron and gamma attenuation coefficients for lucite and masonite using PuF_4 sources and to measure the variation with distance of the neutron dose rate and the gamma dose rate from an unshielded PuF_4 source. This work has been reported by G.L. Helgeson

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INTRODUCTION (Cont'd)

in Document HW-28918.

RECOMMENDATIONS

It is recommended that three barrier-type shields be placed about Task III; the location and extent of the shielding is shown on the drawing on page 14 and also on scope drawing SK-2-867.

It is recommended that one shield be placed at the present Zone I - Zone III barrier. It should extend from the partition wall between Task II and Task III to a point past hood H-13-C. The upper part should be lucite (to obtain both shielding and transparency) and the lower part should be made of masonite. Both sections should be 6" thick. The masonite should extend no higher than 3' - 6" above the floor. The lucite should extend up from the 3' - 6" level as high as practicable (the height will be approximately 7' - 6").

The second shield should be made of a minimum thickness of 3" of masonite and should be placed at right angles to the first shield (the Zone I - Zone III shield) at the partition wall between Task II and Task III. It should extend back from the Zone I - Zone III shield toward the hoods for a distance of at least 1' - 6".

The third shield should be made of masonite 6" thick and 7' - 6" high. It should be placed in Zone III at right angles to the west end of the first shield (the Zone I - Zone III shield) and extend back through hood H-14-CC to a door opening at the south wall.

All masonite thicknesses used above refer to "actual measured thickness", i.e. the overall thickness actually obtained when commerical nominal 1/8" thick masonite sheets are firmly pressed together.

SUMMARY

The required shield thickness was determined by calculating the dose rates at various receiver positions. The locations of the receiver positions is shown on page 14. Results of the calculations are summarized on page 4.

For the Zone I - Zone III shield, receiver positions 1 and 2 were taken to represent points of closest approach on the Zone I side; and, receiver position 3, the closest approach to the control panel.

Dose rates for receiver position 1 for various shield thicknesses are plotted on page 5 for two cases: (1) a single 1600 unit batch in the furnace directly opposite the receiver, and (2) four 1600 unit batches, one in each furnace and one in the mixer. The graph shows that a six inch shield gives a dose rate of about 0.7 mrem/hr for the first case and about 1.8 mrem/hr for the second case. Thus a 6" shield will provide a reasonable factor of safety for the design level of 60 mrem/week for the most likely condition of only one 1600 unit batch in Task III and will not greatly exceed design level for the very unlikely case of four 1600 unit batches in Task III.

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SUMMARY (Cont'd)

Position 5 represents the point of closest approach in Zone I to the radiation from the mixer that just grazes the edge of the Zone I - Zone III shield (in the absence of a shield at the partition wall between Task II and Task III). Addition of a shield at the partition wall between Task II and Task III will reduce the effect of radiation from Task III in Zone I in front of Task II. With 3" of masonite the dose rate at point 5 due to a 1600 unit batch in the mixer will be about 0.7 mrem/hr.

For the shield in the Zone III portion of Task III, receiver position 4 was taken to represent the point of most frequent occupancy closest to the furnaces. The table of results on page 4 shows that 6" of masonite will meet the design level of 60 mrem/week for all conditions involving a single batch in any furnace and will not greatly exceed design level for the unlikely case of three batches in the three furnaces.

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SUMMARY OF ESTIMATED TASK III DOSE RATES
Based on 1600 Units of Metal as PuF_4

ZONE I

Source of Radiation	Receiver Position	Shield Thickness*, In.	DOSE RATE TRANSMITTED Gamma mr/hr	Neutrons mrem/hr	Total mrem/hr
One batch in center furnace.	1	6L	0.31	0.42	0.73
"	1	5L	0.34	0.68	1.0
"	1	4L	0.36	1.08	1.4
"	2	6L	0.19	0.23	0.42
"	3	6L	0.11	0.15	0.26
One batch on conveyor.	1	6L	0.55	0.73	1.3
One batch in mixer.	5	½L	0.24	1.30	1.5
"	5	½L + 3M	0.09	0.57	0.66
Four batches, mixer & 3 furnaces.	1	6L	0.85	0.95	1.8
"	1	5L	0.93	1.59	2.5
"	1	4L	0.99	2.57	3.6

ZONE III

Source of Radiation	Receiver Position	Shield Thickness*, In.	Gamma mr/hr	Neutrons mrem/hr	Total mrem/hr
One batch in furnace 13C.	4	6M	0.32	0.74	1.1
One batch in furnace 13B.	4	6M	0.14	0.33	0.47
One batch in furnace 13A.	4	6M	0.081	0.20	0.28
Three batches in furnaces.	4	6M	0.54	1.27	1.9
One batch in furnace 13B.	6	N	0.99	3.62	4.6
Four batches [illegible] Mixer & 3 [illegible]es.	6	N	2.9	10.6	13.5

*L - Lucite
M - Masonite
N - No shield, - bare source

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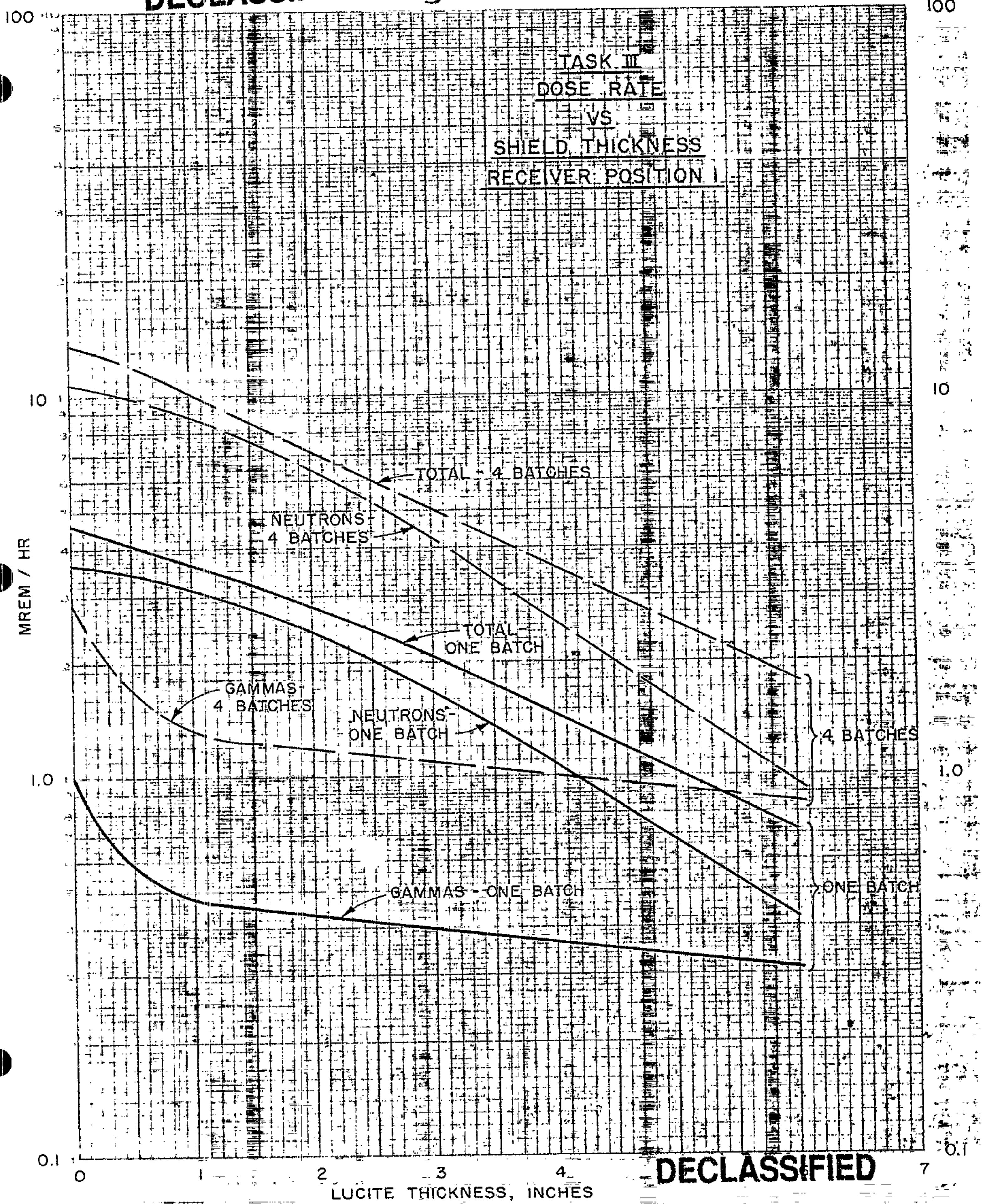

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DISCUSSION

All estimates of dose rates in this report are based on a batch size of 1600 units of metal as PuF_4. Radiation due to hood contamination was neglected because it is expected that this will be small relative to the radiation from a batch of powder and will not contribute significantly to the radiation transmitted through the shield. For an indication of this radiation, reference is made to HW-28090 for surveys of present Task III hoods. Hand exposure in the Task III hoods is not a function of shielding and was considered to be outside the scope of this report.

In order to minimize the total weight of shielding required, consideration was given first to placing the shielding either around the sources or at the hood wall. Preliminary rough estimates of the shield thicknesses, required were based on F. R. Jones' data[4]. The estimated shield thickness was such that shielding at the source would have greatly increased design and maintenance problems. The Project Representatives concurred that the most practical solution was a barrier type shield[8].

Estimates of dose rates in Zone I were made for four receiver positions, single and multiple sources, and various shield thicknesses. The location of each of the receiver positions is shown on page 14. Positions 1 and 2 were taken to represent points of closest approach to the barrier; and, position 3, the closest approach to the control panel. Position 5 was taken as the point of closest approach to the rays just grazing the end of the Zone I - Zone III shield.

Dose rates at receiver position 1 are plotted on page 5 for two cases: (1) a 1600 unit batch in the furnace directly opposite the receiver, and (2) a 1600 unit batch in each furnace and the mixer. The graph shows a six inch lucite shield gives a dose rate of about 0.7 mrem/hr for the first case and about 1.8 mrem/hr for the second case.

For 1600 unit batches, the first case (only one source) is the most likely for the following reasons: For 1600 unit batches at the approved design capacity of the equipment it is not necessary to have more than one batch at a time in the unfired state in Task III. Ordinarily after a mixed 1600 unit batch is one its way to the furnaces it will take longer to mix a second 1600 unit batch than it will to fire the first batch; and, after firing, the neutron flux ceases and the gamma flux decreases appreciably[5]. Hold-up of several batches after mixing would be the only way that more than one batch would be in the furnaces. Hold-up is not desirable, not only from the radiation standpoint, but also from the process and safety standpoints.

With smaller batches, the number to be processed will increase, but the radiation from each batch will decrease in direct proportion to batch size.

Thus 6" of lucite was chosen because, for one 1600 unit batch, it provides a slight factor of safety for the design level of 60 mrem/week, and will not greatly exceed design level for the case of multiple batches.

For the lower, non-transparent part of the Zone I shield, masonite was selected because excess stock is available here and this material is cheaper than lucite. The drawing on page 14 shows that radiation from the batches in the furnaces will have to traverse the masonite obliquely. For 6" thick masonite 3' - 6" high, the length of the minimum oblique path (at the 3' - 6" height) is approximately 7".

DISCUSSION (Cont'd)

Page ~~8~~ 11 of HW-28918 shows that 7" (actual measured thickness) of masonite has the same shielding effectiveness for neutrons as 6" of lucite; and page 21 of HW-28918 shows that 7" of masonite has more shielding effectiveness for gammas than 6" of lucite. Therefore, 6" (actual measured thickness) is satisfactory for the lower masonite section of the Zone I shield.

For receiver position 5, with no shielding at the wall between Task II and Task III, the total dose rate will be 1.5 mrem/hr. This can be reduced to less than the design level of 60 mrem/week by a minimum of 3" of masonite at the wall between Task II and Task III. This shield should be as high as the Zone I - Zone III shield and extend back from the Zone I - Zone III shield for at least $1\frac{1}{2}$ feet.

At the back side of the Task III hoods that will contain powder, operational access will be required for two reasons. The first is passage of personnel to and from the Tasks on either side of Task III. This will require a passageway at the wall. The total dose rate at receiver position 6, due to one 1600 unit batch is 4.6 mrem/hr. The second reason for access is the addition of process materials to the hoods. This could possibly be done when the hoods are empty of powder, however, these operations require only a few minutes per batch. The weighing station for chemical addition will be provided west of the Zone III shielding barrier. If a barrier type shield were used, personnel would have to go through it to reach the hood, and, thus the barrier would not be used when it is needed most. Shielding at the hood would make glove operations difficult. Therefore, project representatives have accepted as the most practical solution, time control of personnel for radiation exposure in Zone III at the back side of the hoods that will contain powder[8].

In order to shield operating personnel at the back side of Task III at those positions where operational access is most frequently required (H-14-DC, H-14-P and H-14-S) a 6" thick masonite barrier should be provided, extending back from the Zone I - Zone III shield through H-14-CC. Thus, at receiver position 4, the total dose rate will be 1.1 mrem/hr with one 1600 unit batch in the nearest furnace, H-13-C.

Calculation of Dose Rates

Both fast neutron dose rates and gamma dose rates were calculated with the following equation:

$$D = \frac{D_o (AF)_t}{d^2}$$

where:

D_o = source strength, dose rate at one foot.

d = distance from source to receiver, ft.

$(AF)_t$ = attenuation factor for shield thickness, t, experimentally determined in HW-28918.

Calculation of Dose Rates (Cont'd)

As indicated in HW-28918, the contribution to the total dose rate due to the slow neutrons produced in attenuating the fast neutrons will be of the order of 6% of the fast neutron dose rate. This is small relative to the total dose rate due to fast neutrons and the gamma rays and was omitted in the calculations here.

The factors in the above equation are discussed in the following sections.

Neutron Source Strength

The neutrons from the fluorine (alpha, n) reaction predominate and are fast (the spectrum peaks at about 0.75 Mev[6]). A negligible amount of self-absorption in the source is to be expected because the source is non-hydrogenous and small. Since the alphas are emitted by the plutonium, it was assumed that the neutron dose rate is directly proportional to the amount of plutonium.

The neutron source strength for the batch containing 1600 units of metal was based on the neutron dose rate vs. distance data for production powder presented in HW-28918. Two sources of production powder were used in HW-28918 for neutron dose rate data: 503.9 units of powder and 836.4 units of powder. Dose rate vs. distance data in air are presented for the 503.9 unit source but not for the larger source. At 12" the dose rate in air for the 503.9 unit source is 30.5 mrem/hr. Taking the weight of metal = 0.759 x weight of powder[7], the corresponding dose rate for a batch of powder containing 1600 units of metal is

$$(30.5)\left(\frac{1600}{503.9 \times .759}\right) = 128.0 \text{ mrem/hr.}$$

Dose rates vs. distance data for the 836.4 unit source is presented on p. 16 ~~13~~, curve A, of HW-28918. Dose rates given by this curve could not be used directly, since this curve was obtained with the source and detector on a concrete floor and the measured dose rate includes neutrons scattered from the floor, particularly at small distances. The correction factor for this scatter effect can be obtained by comparing Curve B, p. ~~13~~ 16, HW-28918, and the curve on p. ~~12~~ 15, HW-28918. Both of these curves were obtained with the same material (H-10 Sweepings) the former with the source and detector on the floor, and the latter with the source and detector in the air. At 12" the "floor" curve reads 30 mrem/hr and the "air" curve 19.9 mrem/hr. The ratio of $\frac{19.9}{30} = 0.66$ is the correction factor for floor scatter to apply to the "floor" curve A, p. ~~13~~ 16 of HW-28918. Therefore, the "air" reading for 836.4 units or production powder is (0.66) (66) = 43.6 mrem/hr at 12". The corresponding reading for a batch with 1600 units of metal is

$$(43.6)\left(\frac{1600}{836.4 \times .759}\right) = 110 \text{ mrem/hr.}$$

A neutron dose rate of 128 mrem/hr at 12" was used as the source strength since this estimate does not include the uncertainty introduced by the floor scatter correction.

Gamma Source Strength

The gammas to be expected are (1) those associated with plutonium, (2) those due inelastic alpha scattering with accompanying gamma emission, (the alpha; alpha, gamma reaction) and (3) those emitted by fission products. The number of gammas due to the first two sources is directly proportional to the amount of plutonium present. The third source is variable and will depend on up-stream processing conditions.

The variations in the gamma dose rates and gamma spectrum presented in HW-28918 indicates that the presence of the third source of gamma makes it impossible to estimate the gamma dose rate of an "average" 1600 unit batch on the measured gamma dose rate from a single smaller batch of powder. At present, we have an insufficient amount of experimental data upon which to base an estimate of the gamma dose rate of an "average" 1600 unit batch.

The gamma dose rate for the 1600 unit batch was estimated in the following manner: Gamma dose rates vs. distance data for three sources is presented on p. ~~23~~ 26 of HW-28918. On the basis of direct proportionality, this data gives the following estimates of gamma dose rate at 12" for a 1600 unit batch:

(1) Curve C reads 7.1 mr/hr at 12" from 503.9 units of powder; the corresponding dose rate for the 1600 unit batch is

$$(7.1)\left(\frac{1600}{503.9 \times .759}\right) = 29.7 \text{ mr/hr}$$

(2) Curve A reads 10.0 mr/hr at 12" from 841 units of powder; the corresponding dose rate for the 1600 unit batch is

$$(8.2)\left(\frac{1600}{841 \times .759}\right) = 20.6 \text{ mr/hr}$$

(3) Curve B reads 13.6 mr/hr at 12" from 836.4 units of powder; the corresponding dose rate for the 1600 unit batch is

$$(13.6)\left(\frac{1600}{836.4 \times .759}\right) = 34.3 \text{ mr/hr}$$

About half of the powder used for Curve B was produced from material that had a high CP reading on the Task II filter boat; the other half had a reading near average. This was taken to indicate that the powder had a higher than average fission product content. Accordingly, an arbitrary estimate of 35 mr/hr at 12" was used for the 1600 unit batch of powder. On the basis of present experimental data, it is felt that this will give reasonably conservative estimates of the average gamma dose rates.

Neutron Attenuation

Neutron attenuation coefficients for lucite, presented on page ~~10~~ 13 of HW-28918, for a source-to-detector distance of 49.1 inches were used, since this distance most nearly approximates the distance involved in Task III.

Neutron attenuation coefficients for masonite presented on page ~~8~~ 11 of HW-28918 for a source-to-detector distance of 30" were used.

Gamma Attenuation

Gamma attenuation factors were based on Studies #3 and #4 reported on p. 2124 of HW-28918. This data was used because the measurements were made with production powder that had the highest gamma energy of those for which a gamma spectrum was determined. Consequently, this should give conservative results.

Distance Attenuation

The dose rate vs. distance data of HW-28918 indicates that both neutron and gamma dose rates closely follow the inverse square law.

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SUMMARY OF CALCULATIONS
ZONE I

Location of Source	Receiver Position	Dist. Factor, Ft^{-2}	Type of Radiation	Shield	Path Length Through Shield Inches	Attenuation Factor	Dose Rates	Total Dose Rate mrem/hr.
One batch in center furnace.	1	0.02825	Gamma	6" Lucite	6	0.317	0.31	
		.02825	Neutrons	"	6	0.116	0.42	0.73
"	1	.02825	Gamma	5" Lucite	5	0.341	0.34	
		.02825	Neutrons	"	5	0.189	0.68	1.0
"	1	.02825	Gamma	4" Lucite	4	0.367	0.36	
		.02825	Neutrons	"	4	0.300	1.08	1.4
"	2	.01778	Gamma	6" Lucite	6.5	0.306	0.19	
		.01778	Neutrons	"	6.5	0.100	0.23	0.42
"	3	.010	Gamma	6" Lucite	6	0.317	0.11	
		.010	Neutrons	"	6	0.116	0.15	0.26
One batch on conveyor.	1	.04938	Gamma	6" Lucite	6	0.317	0.55	
		.04938	Neutron	"	6	0.116	0.73	1.3
One batch in mixer.	5	.01108	Gamma	ca. ½" Lucite	0.5	0.623	0.24	
		.01108	Neutron	"	0.5	0.920	1.30	1.5
One batch in furnace 13A or C.	1	.02308	Gamma	6" Lucite	6.75	0.300	0.24	
		.02308	Neutron	"	6.75	0.088	0.26	0.50
"	1	.02308	Gamma	5" Lucite	5.62	0.326	0.26	
		.02308	Neutron	"	5.62	0.148	0.44	0.70
"	1	.02308	Gamma	4" Lucite	4.50	0.355	0.29	
		.02308	Neutron	"	4.50	0.240	0.71	1.0
One batch in mixer.	1	.00852	Gamma	6" Lucite	11.0	0.19	0.057	
		.00852	Neutron	"	11.0	0.012	0.013	0.07
	1	.00852	Gamma	5" Lucite	9.17	0.23	0.069	
		.00852	Neutron	"	9.17	0.028	0.031	0.10
	1	.00852	Gamma	4" Lucite	7.33	0.27	0.081	
		.00852	Neutron	"	7.33	0.067	0.073	0.15
Four batches: Mixer & Furnaces	1	—	Gamma	6" Lucite	—	—	0.85	
		—	Neutron	"	—	—	0.95	1.8
	1	—	Gamma	5" Lucite	—	—	0.93	
		—	Neutron	"	—	—	1.59	2.5
	1	—	Gamma	4" Lucite	—	—	0.99	
		—	Neutron	"	—	—	2.57	3.6

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SUMMARY OF CALCULATIONS
ZONE III

Location of Source	Receiver Position	Dist. Factor, Ft^{-2}	Type of Radiation	Shield	Path Length Through Shield Inches	Attenuation Factor	Dose Rates	Total Dose Rate mrem/hr.
One batch in Furnace 13C.	4	0.0321	Gamma	6" Masonite	6	0.286	0.32	1.1
		0.0321	Neutron	"	6	0.181	0.74	
One batch in Furnace 13B.	4	0.0144	Gamma	6" Masonite	6	0.286	0.14	0.47
		0.0144	Neutron	"	6	0.181	0.33	
One batch in Furnace 13A.	4	0.0081	Gamma	6" Masonite	6	0.286	0.081	0.28
		0.0081	Neutron	"	6	0.181	0.20	
One batch in Furnace 13B.	6	0.02825	Gamma	None	—	—	0.99	4.6
		0.02825	Neutron	None	—	—	3.62	
Three batches in furnaces.	4	—	Gamma	6" Masonite	6	0.286	0.54	1.9
		—	Neutron	"	6	0.181	1.27	
Four batches Mixer & Furnaces	6	—	Gamma	None	—	—	2.9	13.5
		—	Neutron	None	—	—	10.6	

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