LOFT TECHNICAL REPORT LTR 129-12
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RADIATION LEVELS DURING OPERATION

N. MARINGAS

EG&G Idaho, Inc.

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IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

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AUTHOR	GWA NO.
N. Maringas	
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LOFT APPROVAL Nick Maringas E.K. White 7/16/78 PSB Mgr.	

P&CSB Mgr. RSB Mgr.

SUMMARY

For full-power operation, the four major sources of radiation are:

(1) Neutrons and gamma rays penetrating the sides of the shield tank

(2) Nitrogen-16 activity in the primary coolant

(3) Radiation leakage up and down the space between the reactor vessel and shield tank and scattering to accessible areas

(4) Gamma rays from inelastic scattering of fast neutrons in the core.

These four sources are discussed, and calculated radiation levels in important areas are given in this LTR.

This LTR is issued to ensure the contents, originally an appendix to SDD 1.2.9, are retained for reference.

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RADIATION LEVELS DURING OPERATION

During normal full-power operation there will be four major sources of radiation:

(1) Neutrons and gamma rays penetrating the sides of the shield tank

(2) Nitrogen-16 activity in the primary coolant

(3) Radiation leakage up and down the space between the reactor vessel and shield tank and scattering to accessible areas.

(4) Gamma rays from inelastic scattering of fast neutrons in the core.

These four sources will be discussed and the calculated radiation levels in areas of importance will be given.

A. RADIAL PRIMARY SHIELD

The radial dimensions that were used in the primary shield analysis are given in Table A-I and illustrated on Figure A-1.

The neutron shield tank size was, to some degree, established by structural support considerations and space availability. Rough upper limit calculations are sufficient to show that the neutron flux at the outer surface of the shield tank will be less than 10^3 neut/cm^2-sec. This is lower than required (a) from the standpoint of fast neutron dose in accessible areas during reactor operation and (b) to prevent activation by thermal neutrons in the reactor compartment.

The SCAMP Code[A-1] was used to compute neutron fluxes within the primary shield. This is an S_n transport theory code. A four-group S-6 calculation in radial geometry was used. ANC Nuclear Physics has made comparisons between 34-group transport calculations[A-2] and LIDO reactor experiments and concluded that this method gives adequate results. The thermal neutron flux plotted in Figure A-2 agrees with the thermal flux from the 34-group calculation within 5%. The energy ranges of the four neutron energy groups are (a) Group 1 - 0.821 MeV to 10 MeV, (b) Group 2 - 5.53 keV to 0.821 MeV, (c) Group 3 - 0.532 eV to 5.53 keV, and (d) Group 4 - 0 to 0.532 eV.

Once the thermal neutron flux is known, the gamma ray source strength due to neutron capture in the steel and water is determined using the equation $S_v = \phi_{th} N\sigma_c Y$

where

S_v = gamma ray source strength (γ/cm^3-sec)
ϕ_{th} = thermal neutron flux (neut/cm^2-sec)
N = number density of target element (atom/cm^3)
σ_c = microscopic capture cross section of target element (cm^2/atom)
Y = gamma yield (γ/capture).

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TABLE A-I

RADIAL DIMENSIONS

Item	Material	Inside Radius (in.)	Outside Radius (in.)	Thickness (in.)
1.	Core		12.1	
2.	Flow skirt	12.14	13.8	1.64
3.	Water	13.8	15.0	1.2
4.	Core barrel	15.0	16.0	1.0
5.	Water	16.0	17.0	1.0
6.	Filler	17.0	28.75	11.75
7.	Water	28.75	29.0	0.25
8.	Reactor vessel	29.0	34.5	5.5
9.	Insulation and void	34.5	38.5	4.0
10.	Shield tank inner wall	38.5	40.0	1.5
11.	Shield tank water	40.0	100.5	60.5
12.	Shield tank outer wall	100.5	101.5	1.0
13.	Lead shot	101.5	104.5	3.0
14.	Steel canning plate	104.5	105.25	0.75

The cross sections and capture gamma yields are listed in Table A-II.

TABLE A-II

CAPTURE CROSS SECTIONS AND GAMMA YIELDS

Item	Material	σ_c (Barns)	Energy (MeV)	Y (γ/capture)
1.	Water	0.33	2.2	1.0
2.	Steel	2.53	1.0	0.75
			2.0	0.60
			3.0	0.27
			5.0	0.23
			7.0	0.25
			8.0	0.40

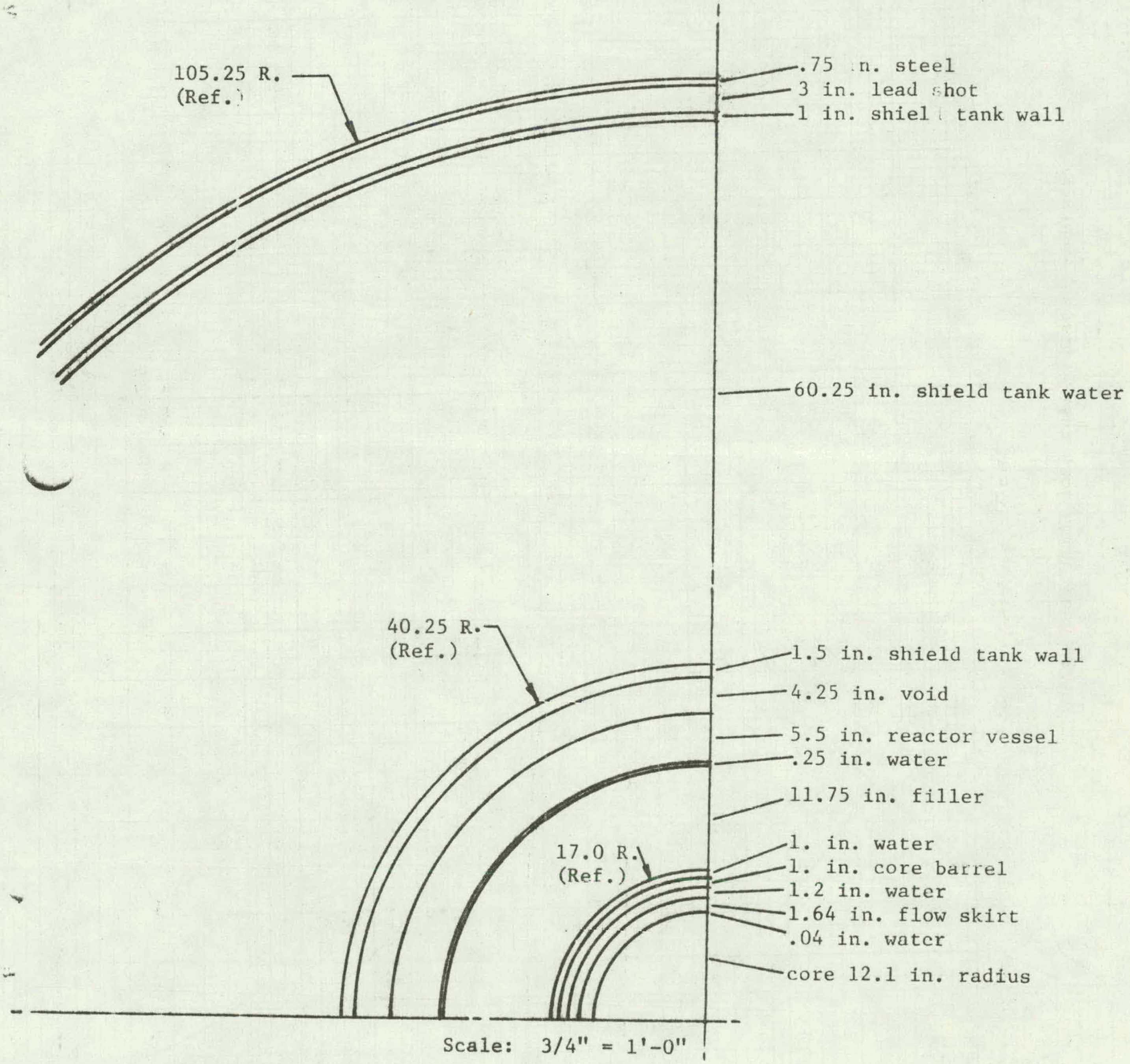

Fig. A-1 Radial material thicknesses.

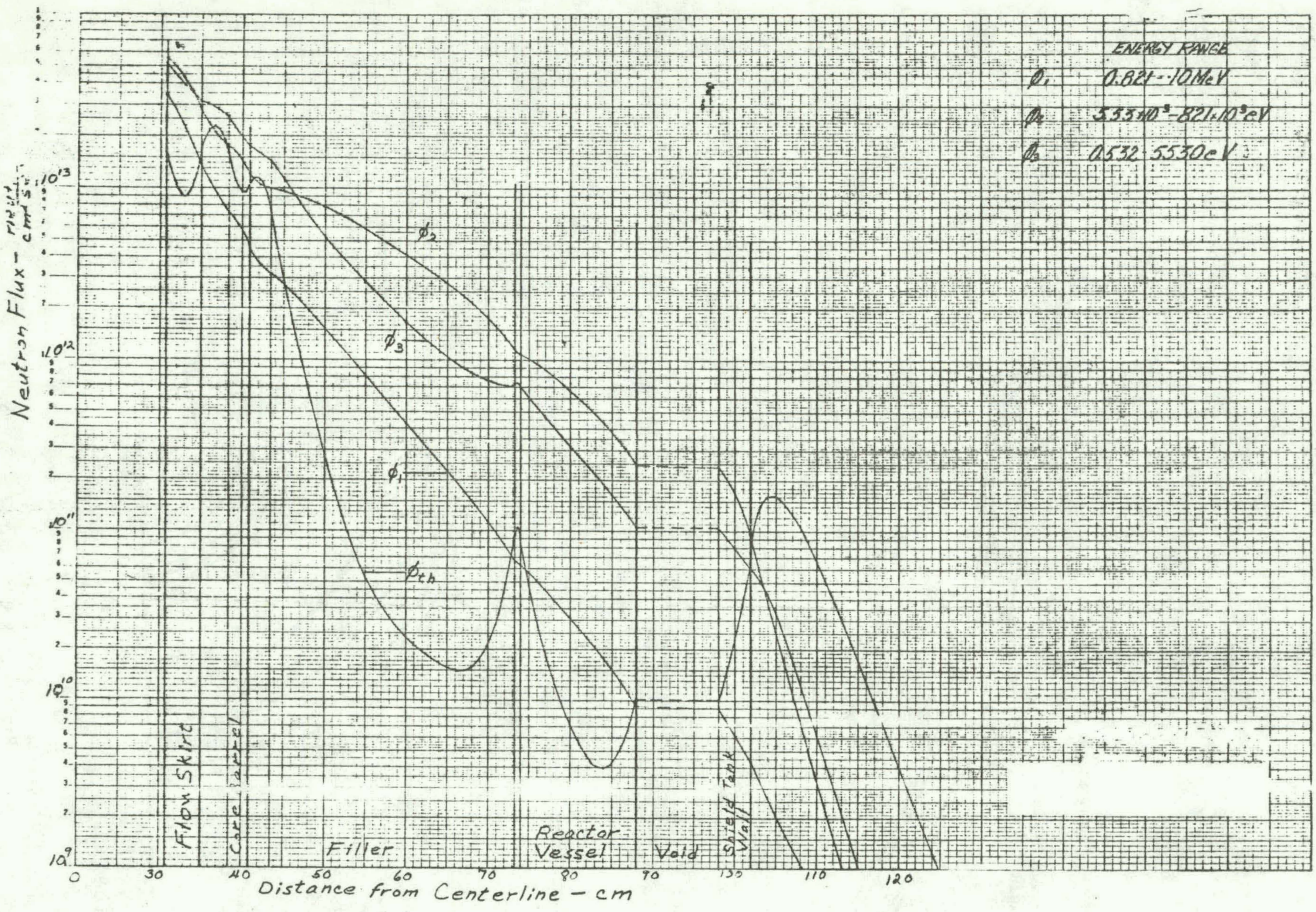

Fig. A-2 Neutron flux plot.

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Thus the gamma ray source strength is determined for the energies of the capture spectrum as a function of radial position. This is used as the source term in the QAD-P5A Code which is used to compute the gamma dose rate. QAD is a point kernel computer code and is described in Appendix C, Section A.

The large amount of steel surrounding the LOFT core is an effective gamma shield, so that core gammas are a very small contributor to the total dose rate. Almost all of the radiation penetrating the sides of the shield tank is due to thermal neutron capture gammas from the steel shield tank inner wall, reactor vessel wall, and the water in the shield tank. On Figure A-3, the dose rate due to radiation emerging from the sides of the shield tank is plotted as a function of radial distance from the reactor centerline.

B. NITROGEN-16 ACTIVITY

The calculation of the N-16 specific activity in the primary coolant and the dose rate from this source is described in Attachment 1. Figure A-4 is taken from this attachment and shows the N-16 dose rate outside the containment vessel.

C. RADIATION STREAMING AND SCATTERING

The Electric Boat (EB) Division of General Dynamics Corporation has calculated the radiation streaming in the gap between the reactor vessel and shield tank inner wall (STIW) and subsequent scattering to accessible areas. This work is reported in LTR 129-2 ~~and~~ is included as Attachment 2.

Since the EB work was done, two changes have been made in the design which reduce the dose rate:

(1) The sump cover and support grating have been removed

(2) The 6-in.-thick polyethylene top hat has been added above the shield tank as shown in Figure 2-1.

Removing the sump cover removes this source of capture gamma radiation and eliminates most of the dose due to neutron and gamma scattering in this area. Some of the neutrons that would have been reflected by the sump cover may scatter out of the sump and eventually travel to occupied areas. At least one additional scattering is required; however, this source is expected to be insignificant.

Calculations have been made to determine the effect of the top hat on the dose rate at the air-cooled condenser and 50 ft from the reactor vessel centerline. The dose rate due to neutrons passing through the top hat will be reduced to approximately 2 mrem/hr. Gamma radiation due to neutron capture in the upper pressure vessel (PV) will be reduced to 25 mrem/hr by the top hat. Since there is a gap between the top hat and the top of the shield tank, this is another source of neutron flux. The methods outlined in Attachment 2 were used to calculate the dose rate due to neutrons scattering downward from the inclined part of the reactor vessel and scattering again off the shield tank top. The calculated dose rate at the air-cooled condenser

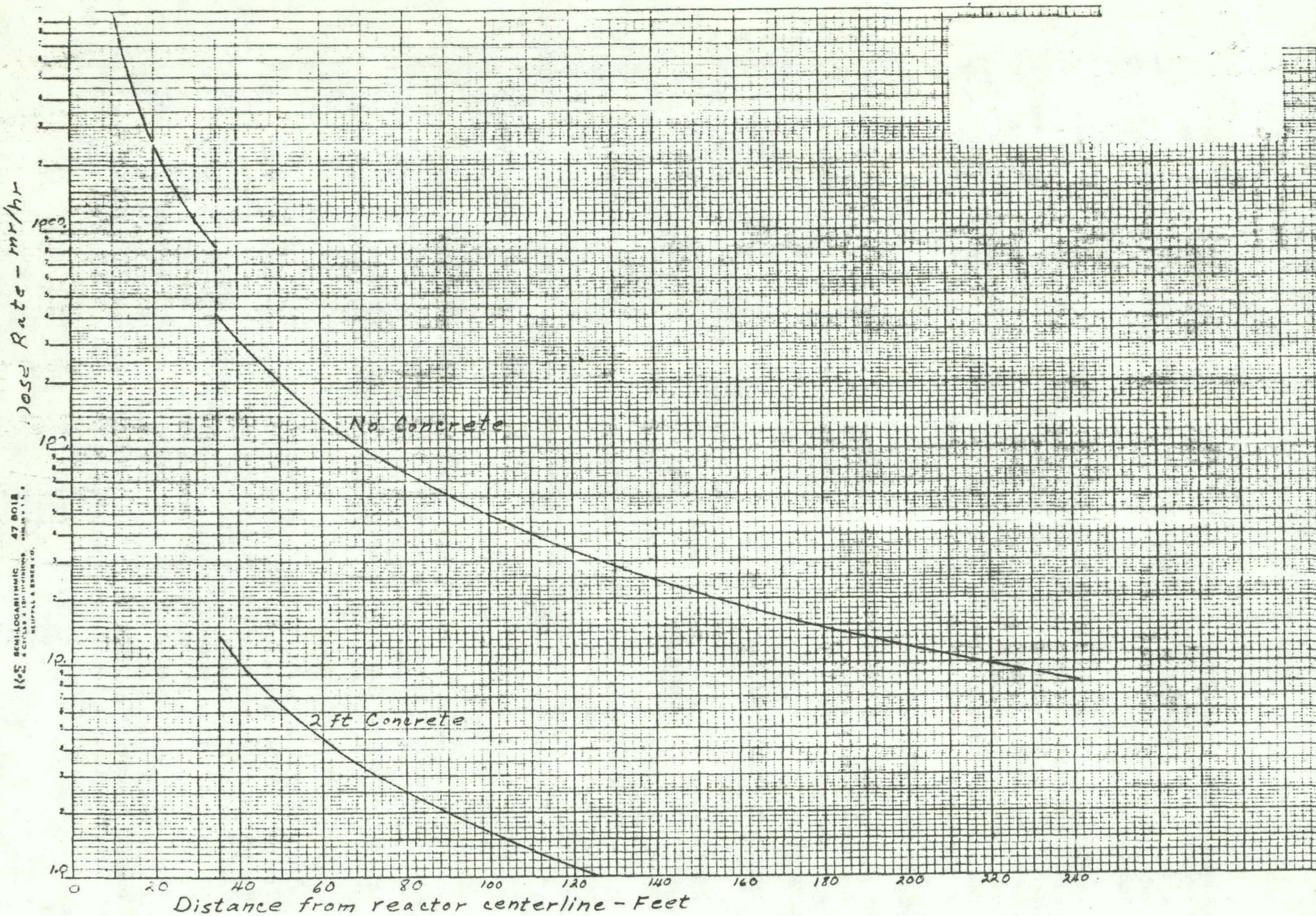

Fig. A-3 Gamma dose rate - primary sources.

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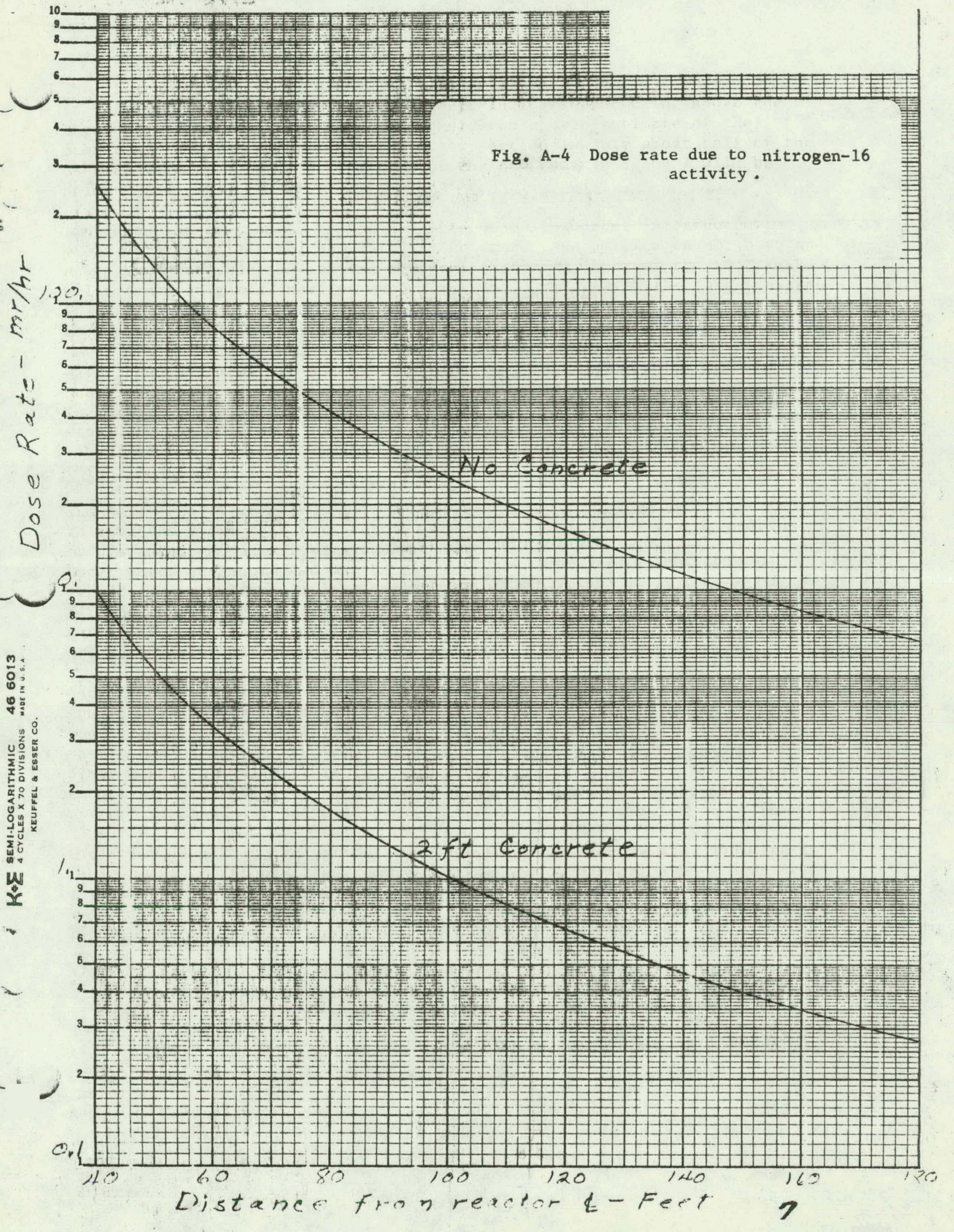

Fig. A-4 Dose rate due to nitrogen-16 activity.

is 7.5 mrem/hr. Thus, with the modifications that have been made, the dose rate at the air-cooled condenser due to steaming and scattering is as shown in Table A-III.

TABLE A-III

DOSE RATE DUE TO STREAMING AND SCATTERING

Item	Radiation Source	Dose Rate (mrem/hr)
1.	Neutron scatter by shield tank extension	0.41
2.	Capture gammas from STIW extension and lower PV	34.0
3.	Neutrons through top hat	2.0
4.	Neutrons scattering under top hat	7.5
5.	Capture gammas from upper PV	25.0
	TOTAL	68.91

The dose rate as a function of distance has been estimated for these sources assuming $1/r^2$ attenuation. This should be reasonably accurate for the distances involved, and since the streaming and scattering dose rate is less than 20% of the total, the error should not be important. These results are plotted on Figure A-5.

D. INELASTIC SCATTERING

Conservative assumptions were made to get an upper limit to the gamma dose rate from inelastic scattering. With this approach, the dose rate was calculated for a point 40 ft from the containment centerline with no concrete shielding. The calculated dose rate was 9 mrem/hr. This compares with 315 mrem/hr for all other primary sources at the same point. The dose rate from inelastic scattering will be about the same fraction of the total at other distances.

The cross section for inelastic scattering in iron has a threshold at 0.85 MeV, increases with energy to about 4 MeV, and is constant above that energy with a value of 1.4 barns. Goldstein[A-3] lists energies for the gamma rays emitted ranging from 0.12 to 3.52 MeV.

Two simplifying assumptions were made:

(1) A cross section of 1.4 barns was used for all the neutrons in Group 1 of the four-group neutron fluxes plotted in Figure A-2

(2) One 3-MeV gamma is emitted in each inelastic scattering.

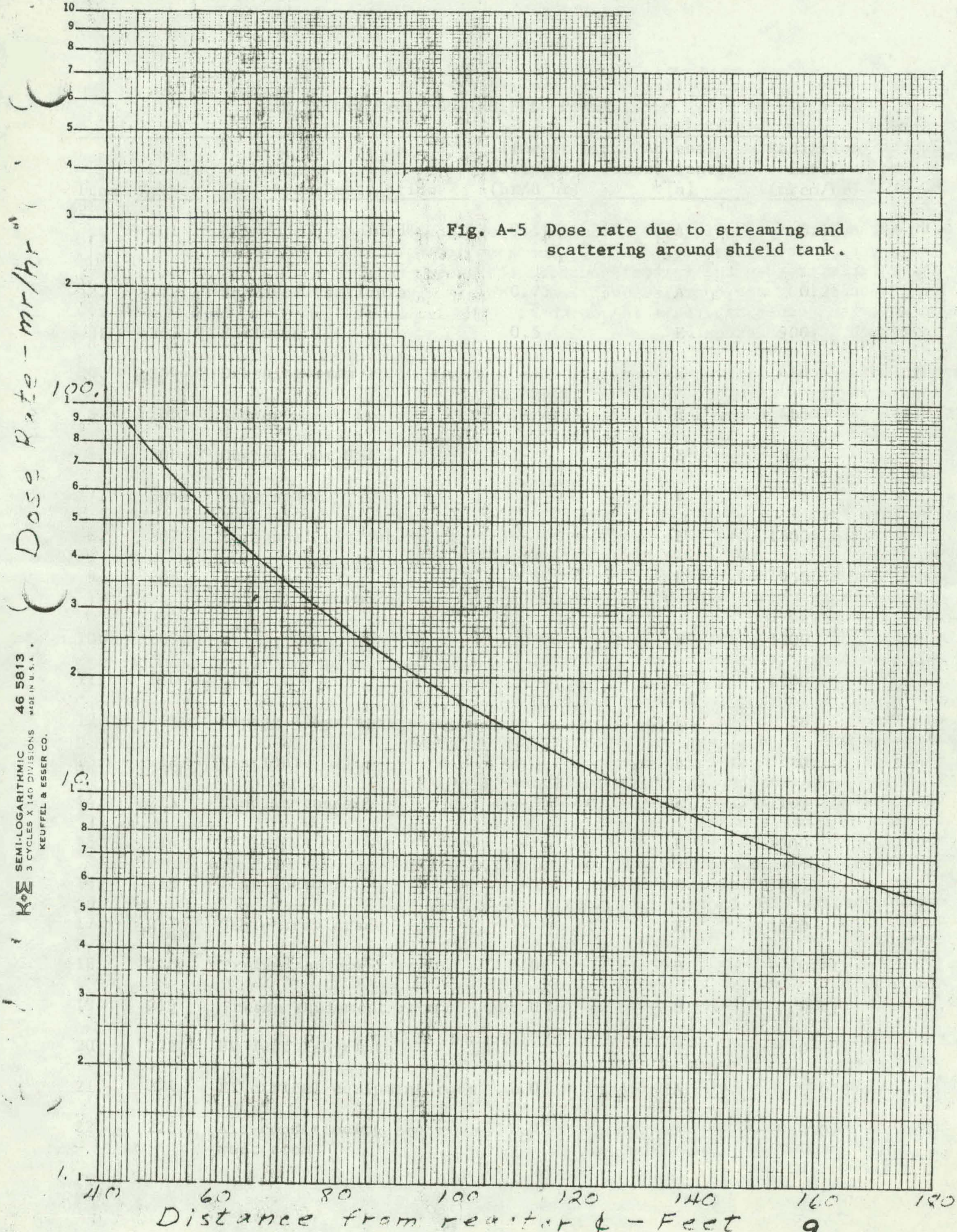

Fig. A-5 Dose rate due to streaming and scattering around shield tank.

The first assumption is certainly an upper limit. The first energy group is all the neutrons above 0.821 MeV so it includes everything above the threshold. Probably it leads to a considerable over-estimate of the number of reactions. At 2 MeV the cross section is only about half of the assumed value, and a major fraction of the neutrons in Group 1 will be below 2 MeV.

The second assumption is not an absolute upper bound but is expected to yield very conservative dose rates. The gamma rays emitted cannot have an energy greater than the initial neutron; therefore, many of the reactions will result in gamma energies much less than 3 MeV. With the large thickness of water and other materials in the shield, the low-energy gammas are attenuated to a much greater extent.

With these conservative assumptions, the calculated dose rate from inelastic scattering is 9 mrem/hr, less than 3% of the total. For areas where there is concrete shielding, the fraction of the total dose will be even less since the energy of the inelastic scattering gammas is relatively low.

E. TOTAL DOSE RATE

The data from Figures A-3, A-4, and A-5 have been combined in Figure A-6 to give the total dose rate outside the containment vessel as a function of distance. No credit was taken for attenuation by equipment. Thus, the upper curve in Figure A-6 may be considered an upper limit; in most directions the dose rate will be lower. Curves are also included to show the effect of 2 ft of concrete. There will be a 7-ft-high, 2-ft-thick concrete wall surrounding the containment vessel, and since most of the radiation sources are at a higher elevation, the wall will be ineffective as a shield.

Additional shielding is being considered to provide access to the air-cooled condenser. One of the possibilities is to extend part of the 2-ft-thick concrete wall to a higher elevation. If this is done, Figure A-6 shows that the dose rate at the closest corner of the air-cooled condenser will be 11 mrem/hr. Actually, this is a considerable overestimate. The blowdown suppression tank will be between many of the radiation sources and the air-cooled condenser and will provide effective shielding.

Radiation levels in the various rooms of Building TAN-650 are tabulated in Table A-IV. Occupancy requirements during normal operation have been established by LOFT Operations Branch and are also listed in Table A-IV.

F. REFERENCES

A-1. Letter, C. L. Beck to R. S. Marsden, "Input Description of SCAMP Codes (S_n Codes for the Analysis of Multigroup Problems), Beck-2-68 (May 17, 1968).

A-2. Letter, R. A. Grimesey to M. N. Monson, "Thermal Flux at Power Range Detectors, Gri-2-71 (March 10, 1971).

A-3. H. Goldstein, Fundamental Aspects of Reactor Shielding, Addison-Wesley Publishing Co., Inc., Reading, Mass. (1959) p 74.

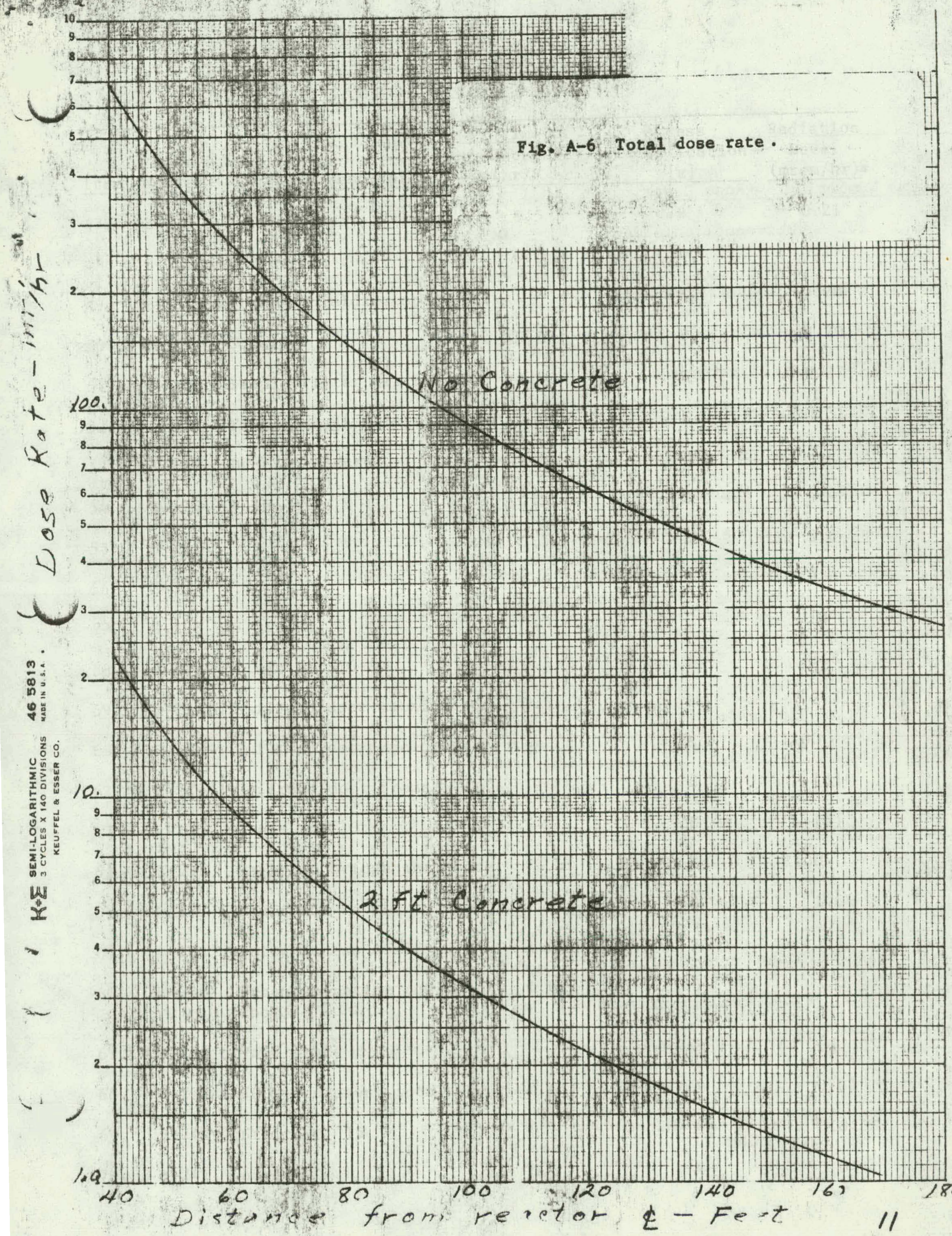

Fig. A-6 Total dose rate.

TABLE A-IV

RADIATION LEVELS DURING FULL POWER

Item	Room Number	Room Description	Time of Occupancy (hr/8 hr)	Access Classification [a]	Radiation Level (mrem/hr)
1.	201	Personnel shielded entrance	0.5	A	0.17
2.	202	Shielded vestibule	0.75	A	0.25
3.	203	Hallway	0.5	E	900
4.	204	Dressing room	–	E	460
5.	205	Shower	–	E	460
6.	206	Change room No. 1	–	E	570
7.	206A	Pipe space	–	E	16
8.	207	Personnel airlock No. 1	–	E	1300
9.	208	Personnel airlock shielding room	0.5	E	950
10.	209		–	E	1300
11.	210		–	E	1300
12.	211	Piping labyrinth	–	E	26
13.	212	Vestibule	2.0	B	0.1
14.	213	Conduit tunnel	–	E	1100
15.	214		–	E	1300
16.	215	Test chamber	–	E	[b]
17.	217	Cable tray space	–	E	1300
18.	218	Preamp equipment room	8.0	B	0.41
19.	219	Preamp equipment room	8.0	B	0.41
20.	222	HV duct labyrinth	–	E	950
21.	224	Electrical equipment room	2.0	A	0.003
22.	225	Air-conditioning equipment room	2.0	A	0.07

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TABLE A-IV (contd.)

Item	Room Number	Room Description	Time of Occupancy (hr/8 hr)	Access Classification [a]	Radiation Level (mrem/hr)
23.	226	Toilet	0.75	B	0.31
24.	227	Duct enclosure	-	E	26
25.	229		-	E	4.2
26.	B-105	Manuever space	1.0	B	0.51
27.	B-106	Air intake	0.5	B	0.20
28.	B-107	Air intake	0.5	B	0.22
29.	B-201	Electrical equipment room	2.0	A	0.23
30.	B-202	Hallway	1.0	A	0.23
31.	B-203	HV and piping equipment room	4.0	B	2.1
32.	B-203A		1.0	B	0.32
33.	B-203B		0.5	B	0.42
34.	B-204	Stair No. 5	0.5	B	1.7
35.	B-205	Janitor closet	1.0	B	1.3
36.	B-206	Piping labyrinth	-	E	4.2
37.	B-207	Stair No. 6	1.0	C	2.6
38.	B-208	Equipment access shaft	1.0	B	0.30
39.	B-209	Shielded roadway	1.0	B	1.7
40.	B-211	Personnel airlock No. 2	0.5	B	4.2
41.	B-212	Cable labyrinth	-	E	4.2
42.	B-213	Sample control center	0.5	B	0.43
43.	B-214	CSM sample room	0.5	B	0.77
44.	B-215	Sample room	4.0	A	0.19
45.	B-216	Locker room	1.0	B	0.29
46.	B-217	Change room	1.0	B	0.26

TABLE A-IV (contd.)

Item	Room Number	Room Description	Time of Occupancy (hr/8 hr)	Access Classification [a]	Radiation Level (mrem/hr)
47.	B-218	Loading area	0.5	B	0.21
48.	B-219	Filter fan room	0.5	B	0.19
49.	B-220	Filter shielding space	-	E	0.20
50.	B-221	Corridor	0.5	B	0.20
51.	B-222	Sample filter train room	1.0	B	0.27
52.	B-223	Filter train chamber vault	-	E	0.31
53.	B-224	Duct enclosure	0.5	B	4.4
54.	B-225	Valve pit	0.5	B	4.4
55.	B-225A		0.5	B	3.6
56.	B-225B		0.5	B	3.6
57.	B-226	Stair No. 9	0.5	C	[c]
58.	B-226A	Stair No. 10	0.5	B	3.8
59.	B-227	Railroad door machine room	0.5	B	2.7
60.	B-228	Railroad door enclosure	-	E	1100
61.	B-229	Railroad door frame	-	E	[d]
62.	B-230	Stair No. 13	-	E	[c]
63.	B-231	Railroad bridge enclosure	-	E	1100
64.	B-233	Equipment room	1.0	B	1.0
65.	B-234	Valve access aisle	1.0	B	1.0
66.	B-236	Decontamination equipment room	1.0	B	1.0
67.	B-238	Void space	-	E	[d]
68.	B-239	ECCS equipment room	1.0	A	0.01
69.	B-240	Stair No. 15	0.5	A	0.04
70.	B-241	Airlock	0.5	A	0.04

TABLE A-IV (contd.)

Item	Room Number	Room Description	Time of Occupancy (hr/8 hr)	Access Classification [a]	Radiation Level (mrem/hr)
71.	B-242	Vestibule	0.5	C	[c]
72.	B-243	Tank well	0.5	A	0.01
73.	B-244	Stair No. 14	0.5	A	0.04
74.		Building TAN-630	8.0	A	0.1
75.		Air-cooled condenser	0.5	C	310

[a] A = Full-time occupancy
B = Full-time access
C = Limited access
D = Exclusion
E = Exlusion by administrative control - no access.
[b] Discussed in this Appendix.
[c] Not determined, depends on air scattering from outside.
[d] Not determined.