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DOSE RATES
for
CYLINDRICAL SOURCE VOLUMES
from
FREQUENTLY ENCOUNTERED FISSION PRODUCTS
through
LEAD, IRON, and CONCRETE

by

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DOSE RATES FOR CYLINDRICAL SOURCE VOLUMES
FROM FREQUENTLY ENCOUNTERED FISSION PRODUCTS
THROUGH LEAD, IRON, AND CONCRETE

H. A. Moulthrop, D. T. Vladimiroff

ABSTRACT

Gamma dose rates, including Bremstrahlung, derived by use of the ISOSHL D Computer Codes I¹ and II² are presented for a series of twelve cylindrical vessels of graduated sizes containing an aqueous solution for each of ten common fission product sources. Through the use of tables and charts included herein, each of these 120 combinations of source and vessel geometry are further related to shielding materials of lead, iron, concrete, and plastic. The calculations include eighteen different shielding arrangements from which dose rates versus shielding thicknesses are plotted. The graphs as developed from these data are presented for each of the ten isotope sources. Volumes for which dose rate data is given vary from one milliliter to 15,600 gallons.

Dose rates with iron and lead shielding are calculated for a 3-foot distance from the near side of the vessel and those with concrete are for 10 feet.

Graphs are also presented for determining the dose rate at other distances and for interpolating dose rates for process vessels of intermediate volumes.

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INTRODUCTION

Recent publication of shielding computer codes ISOSHLD I¹ and ISOSHLD II² has provided a stimulus for the generation of shielding and radiation dose rate data related to the chemical processing of nuclear materials.

The preponderance in chemical processes of radiation sources that are dispersed in an aqueous solution within a cylindrical container have prompted an early application of the new codes to such sources.

An examination of the history of requests for shielding information from the Chemical Processing Plants and associated design projects has indicated the need for tabulating dose rates from a graduated variety of cylinder sizes when filled with a solution of one of the several more common fission products and when shielded with one of the more commonly used radiation shielding materials.

Although this need has been evident since the early days of atomic plant operation, the complexity of relating the various source size geometries to the several source isotopes discouraged manual calculations. The added need for relating each of these many calculated relationships between an isotope and a volume to each of the several common shielding materials in not just one but in a number of separate thicknesses has for years further complicated and discouraged the making of these calculations.

Availability of the ISOSHLD Computer Codes brought the mechanics of these many calculations within the ~~range~~ of feasibility and led to their performance as reported herein.

A basic purpose of this document is to provide design engineers and their technical assistants with information sufficient for making an adequate approximation of expected dose rates during early stages of design scoping activity. In being able to determine these dose rates within a degree of accuracy commensurate with his immediate need by use of tables or charts, the engineer can avoid time delay associated with seeking advice of shielding specialists. More exact calculation can thus be reserved until final source dimensions and isotope inventories are determined.

DISCUSSION

RADIATION SOURCES

The specific fission products included in the data processing program upon which this report is based are shown in Table 1. Their selection was determined by a review of shielding requirements within fission product separations plants which indicated these ten isotope sources presented the most commonly encountered shielding problems.

A majority of these radiation sources include not only the parent isotope but also one or more daughters which contribute to the total emitted radiation.

For the unit strength of each source as used in the computed shielding, the value taken is that amount of the parent isotope which in equilibrium with its daughters has a total activity of one curie or 3.7×10^{10} disintegrations/sec., as represented by this rate of beta emissions. All gamma radiation associated with these disintegrations are included in this total curie of each radiation source. Reference to one of the ten sources by the parent should thus be regarded as also including the radiation of the daughters present in equilibrium amounts with the parent.

In some plant situations a source of radioactivity is expressed in curies of the parent isotope only with no mention of the daughter contributions which are none-the-less existent. Table 1 thus provides for conversion between source expressed as curies of parent isotope only and source expressed as total curies which includes also the curie contribution from daughters which exist in equilibrium with one curie of the parent isotope. For convenience Table 1 also includes that fraction of each total curie of a parent-daughter equilibrium source which is contributed by the parent isotope only.

SOURCE VOLUMES

Twelve source volumes of cylindrical shape were used in the computer calculations. These are shown in Table 2 together with the diameter and the height or length of the cylindrical volume. The volumes vary from one millimeter to 15,000 gallons to cover the wide range of vessels from small laboratory samples to tank car shipments.

Practical limitations of available computer machine time precluded a number of variations in the geometry of the selected cylindrical source volumes. Dose rates from other desired geometries can be derived with reasonable accuracy by interpolating the graphed data of these volumes as presented in Figures 4 and 5 and applied to Figures 6 through 15.

SHIELDING ARRANGEMENTS

Eighteen shielding arrangements were selected for relating the dose rates, source volumes and the radiation sources to iron, lead, and concrete shielding. These shield variations are shown in Table 3 which also includes 1/16-inch plastic, 1/2-inch plastic, and 1-foot of water for approximating a minimum shield, a glove box transparent panel, and neutron shielding respectively.

For the shielding arrangements of both lead and concrete, as displayed in Figures 6B - 15B and 6C - 15C, a 1/4-inch thickness of iron is included to allow for the shielding of a glove box or vessel wall which will normally be present when lead or concrete are used for supplemental shielding.

Computations for all of the shielding arrangements were made for the one gallon, the 150 gallon, and the 5,000 gallon source volumes with each of these shield-volume cases being computed for each of the ten selected isotope sources. In addition, the dose rate for each of the other nine source volumes with four shielding arrangements was computed. Tables 6 through 15 and Figures 6 through 15 present and display these relationships of sources, volumes, and shielding to dose rate.

DISTANCES VERSUS DOSE RATE RELATIONSHIPS

The dose rate computations for all shielding arrangements other than concrete are determined for a distance of three feet from the side of the source volume. This distance in all cases is measured in a plane perpendicular to the cylindrical axis of the source volume. For the concrete shielding a distance of 10 feet is used to avoid complications in those instances where the shielding thicknesses exceed three feet.

To provide a basis for converting the three foot or ten foot standard distance used in the calculations to such other distances at which data or dose rates may be needed, information on distance versus dose rate relationships for a variety of source volumes was developed by use of the ISOSHL D Computer Code. This is presented in Figure 1. Empirical data from actual measurements was used for supplying similar information for distances of less than three feet from the source. This is presented in Table 5 and in Figure 3. The computer code was not used for distances of less than three feet since the point-kernel integration on which the ISOSHL D Code is based tends to break down as larger size sources are closely approached.

DETERMINING DOSE RATE AT DISTANCES GREATER THAN THREE FEET FROM SOURCE

The variation of dose rate with distances in excess of three feet as shown in Figure 1 is expressed as a reduction factor in terms of the dose rate at three feet from the side of the source volume.

Table No. 4 for convenience in usage presents data from Figure 1 as the reduction factor in terms of the dose rate at three feet for distances of six feet, ten feet, and other distances in ten foot increments, up to 50 feet. These data from Table 4 are plotted in terms of volume on Figure 2 from which can be used for approximating the distance radiation factor for volumes varying from one gallon to 15,000 gallons. This distance reduction factor, thus derived, when applied to its respective source volume will convert a dose rate at distances up to 50 feet to the dose rate at the base distance of three feet as measured from the side of the source. The three foot dose rate is determined by dividing the known dose rate at a given distance by the reduction factor for this distance as given in Figure 1 or Figure 2. This is expressed by the general formula:

$$\text{Mr/hr at 3 ft} = \text{mr/hr at x ft} / \text{reduction factor for x ft.}$$

Example: The dose rate at ten feet from the side of a 150 gallon vessel is known to be 10 mr/hr. What is the dose rate at three feet?

The dose rate existing at three feet from the side of the vessel may be found by dividing 10 mr/hr by 0.15 which is the factor for a 150 gallon volume given in Figure 2.

$$\text{Thus, } \frac{10 \text{ mr/hr}}{0.15} = 66.7 \text{ mr/hr.}$$

So, the dose rate at three feet from the side of the source may be concluded to be approximately 65 mr/hr.

The base dose rate at three feet from the side of the source also may be readily converted to the corresponding dose rate at a distance greater than three feet. This is done by multiplying the known base dose rate at three feet by the reduction factor for the greater distance as obtained from Figure 1 or 2.

Example: The dose rate at three feet from the side of a 2,000 gallon tank is 250 mr/hr. What is the dose rate at a distance of 28 feet?

From Figure 1, the reduction factor for a distance of 28 feet from that at three feet is shown to be 0.04. Thus, $250 \text{ mr/hr} \times 0.04 = 10 \text{ mr/hr}$ at 28 feet.

DETERMINING DOSE RATE AT DISTANCES OF LESS THAN THREE FEET FROM SOURCE

The empirical data used in determining the dose rate versus distance relationship for distances of less than three feet from the side of the source is presented in Table 5. This data is displayed in Figure 3 showing variation of dose rate for source sizes ranging from a point source to a four foot diameter by 25 foot tank. From Figure 3 any dose rate for a distance of less than three feet can be obtained by multiplying the dose rate at three feet by the appropriate increase factor. The relationship can be expressed by the following general formula.

Dose Rate at distance less than 3 feet = Dose rate at 3 feet x increase factor.

Note: Increase factor for the lesser distance is obtainable from Figure 3.

Example: The dose rate at three feet from a drum of source solution is 25 mr/hr. The drum has an 18-inch diameter and is five feet high. What is the dose rate at 12 inches?

This source size corresponds to the source volume of Curve 2 on Figure 3. From Curve 2 at 12 inches the increase factor in terms of the dose rate at three feet is 3.2. Thus, $25 \text{ mr/hr} \times 3.2 = 80 \text{ mr/hr}$ at 12 inches from the side of the drum.

For source volumes intermediate to the plotted curves, increase factors may be approximated by interpolation from Figure 3.

VOLUME VERSUS DOSE RATE RELATIONSHIPS

One of the continuing problems of dose rate and shielding determinations is the extent to which self-shielding within process vessels reduce the dose rate from the contained source material. Although no attempt was made in this report to define the mathematical relationships which exist between tank dimensions and self-shielding, Figures 4 and 5 do display this relationship as it relates to the twelve graduated tank sizes listed in Table 2.

These twelve volumes were originally selected following a survey among plant engineering groups of the specific dimensions of vessels which if included in the computer program would best serve their actual needs. Thus, from a practical engineering point of view, the volume versus dose rate relationship shown herein for each of the ten radiation sources should be adequate for normal useage. Tanks varying greatly from these in their length or diameter with respect to volume can be studied as a special case.

Figure 4 displays the dose rates from the ten radiation sources for source solutions of one curie/gallon in vessels of minimum or essentially no shielding. Dose rates through 1/16-inch polyethylene as given in Tables 6 through 15 provide the source data shown in Figure 4.

A similar plot of dose rates through vessels with a wall of 1/4-inch iron plus 1-inch of lead was also made from data given in Tables 6 through 15. This is displayed in Figure 5.

The non-linearity of the dose rate curves of Figures 4 and 5 reflect the effect of the self-shielding as the volume of the source solution increases.

These curves may also be used to increase the accuracy of dose rate interpolations between plotted volumes as shown in Figures 6 through 15. Figures 4 and 5 serve the further function of permitting a rapid appraisal as to which among the ten sources in equal curie quantities contribute the greater dose rate and consequently will govern shielding considerations.

SHIELDING VERSUS DOSE RATE RELATIONSHIPS

Tables 6 through 15 present dose rates obtained with the ISOSHLTD computer program for each of the ten radiation sources in each of the twelve graduated source volumes. The tables also further relate the dose rate from each of these source-volume combinations to one or more of the eighteen selected shielding arrangements. For the 36 source volumes of one gallon, 150 gallons, and 5,000 gallons, the dose rates were computed for all eighteen shielding arrangements. Data from the tables relating to lead, iron, and concrete are also presented graphically in Figures 6 through 15.

Figures with an A suffix from 6A, 7A, 8A through 15A show the dose rates for each of the isotope sources on separate graphs, using iron as a shield in thicknesses varying from 1/4-inch to 2 inches. Curves on each graph relate the dose rate to source volumes varying from one milliliter to 15,000 gallons. Figures with a B suffix 6B, 7B, 8B through 15B present the same dose rate relationships using lead in thicknesses varying from 1/2-inch to 8 inches. Similarly, Figures with a C suffix 6C, 7C, 8C through 15C relate these dose rates to thicknesses of concrete varying from 6 inches to 6 feet.

For the concrete shielding, dose rates are computed at a distance of 10 feet from the source to allow for the wide range of shield thickness. All other dose rates are computed at a distance of three feet from the side of the source.

HOW TO DETERMINE DOSE RATE AND SHIELDING

Determination either of the dose rate for a prescribed shielding arrangement or shielding required for a specific dose rate to be realized can be made from reference to the computed relationships of dose rate to volumes, shielding, source, and distance. Basic approach to the determination of total dose rate is the independent calculation of the dose rate contributed by each of the radiation sources individually. The sources for which calculations can be made from the data included in this report is limited to those listed in Table 1.

The dose rate contributed by any one of these sources can be determined by:
1) reference to the particular chart among Figures 6 through 15 which relates the specific radiation source to the shield material being

considered; and 2) reading of the dose rate at three or ten feet for the applicable volume of the source as shown on this chart. Interpolation of dose rate between the plotted volume curves, if needed, is done as described under Volume Versus Dose Rate Relationships.

Adjustment of this derived dose rate for distance from the particular radiation source may now be made, if needed, by reference to Figures 1 through 3, as described under Distance Versus Dose Rate Relationships.

More than one radiation source may and usually does contribute to the total dose rate for which a determination is being sought. The total dose rate is determined by simple addition of the individual dose rates from each specific source to give the actual dose rate from the composite source material.

If the sources contributing to the common total dose rate are located in different vessels or containers, a separate distance adjustment may be required for each of the radiation sources.

Example: A 150-gallon steel tank with 1/2-inch lead cladding contains an aqueous solution in which Sr-90 and Ru-106 are each present in equilibrium with their daughters. The Sr-90 and its decay products are present in a total concentration of 4.11 curies per gallon. Total concentration of the Ru-106 and its decay products is 0.27 curies per gallon. What is the dose rate two feet from the side of the vessel?

From Figure 7B, the Sr-90 radiation source in a concentration of one curie per gallon for a 150 gallon volume at three feet from the vessel gives 20 mr/hr through 1/2-inch of lead. Similarly from Figure 11B, a Ru-106 radiation source in a concentration of one curie per gallon for a 150-gallon volume through 1/2-inch of lead gives 400 mr/hr at three feet.

The dose rate contribution from the 4.11 curies per gallon of Sr-90 and daughters present is thus:

$$\frac{20 \text{ mr/hr}}{\text{Curie/gal}} \times 4.11 \text{ curies/gal} = 82 \text{ mr/hr}$$

The corresponding dose rate contribution from the 0.27 curies of Ru-106 and daughters is:

$$\frac{400 \text{ mr/hr}}{\text{Curie/gal}} \times 0.27 \text{ curies/gal} = 108 \text{ mr/hr}$$

Total dose rate at three feet is therefore: 82 mr/hr + 108 mr/hr = 190

To determine the dose rate at two feet instead of three feet, refer to Figure 3 for the increase factor for distances of less than three feet. On it curve 2 which represents the volume that most nearly resembles the 150 gallon tank, gives a dose rate increase factor of 1.5 at two feet. So the dose rate at two feet = 190 mr/hr x 1.5 = 285 mr/hr.

HOW TO ADD SHIELDING FOR SPECIFIC DOSE RATES

A common shielding concern is determination of additional shielding that should be placed in a known radiation field to reduce the dose rate to some specified value. This determination also can be made by reference to the shielding curves of Figures 6 through 15, but in using these shielding curves for determining the thickness of additional shields allowance should be made for any "hardening" of the gamma spectrum from existing shields. The "hardened" spectrum results from the preferential attenuation of lower energy gamma radiation in passing through shields and reflects the higher average gamma energy of the emerging radiation as compared with the unshielded radiation. It accounts for the greater non-linearity of the shielding curves for the lower values of shield thicknesses.

Example: The dose rate of 285 mr/hr at two feet from the 150 gallon tank of the previous example is considered too high. It is desired to construct a concrete wall in front of the tank so that the dose rate at this two foot distance is not more than 5 mr/hr. How thick should the wall be?

The factor by which this excessive dose rate must be reduced is thus:

$$\frac{5 \text{ mr/hr}}{285 \text{ mr/hr}} = 0.017$$

The thickness of concrete required to reduce the gamma radiation by a factor of 0.017 can be obtained directly from the 150 gallon curve of Figures 7C and 11C. To insure that allowance is made for hardening of the spectrum by the existing 1/2-inch of lead, the application of these secondary shield curves is limited to thicknesses of the second shield which are at least equivalent to the existing shield.

From Figures 7B and 11B for the existing shield of 1/2-inch lead, dose rate for the 150 gallon volume is 20 mr/hr for Sr-90 and 400 mr/hr for Ru-106. Equivalent concrete thicknesses for these dose rates on Figures 7C and 11C are 4.5 inches for Sr-90 and 2 inches for Ru-106.

Using a portion of the 150 gallon curve at thicknesses greater than 4.5 inches of concrete to allow for the hardening effect, the additional concrete required to reduce the dose rate by a factor of 0.017 or 1.7×10^{-2} is shown on Figure 7C to be 8.5 inches for Sr-90 and on Figure 11C to be 15 inches for Ru-106. Inasmuch as the Sr-90 dose rate contribution is small compared to that of the Ru-106, a 15 inch concrete wall is thus required.

TABLE 1

Radiation Source Total Curies Concentration of 1 Curie/Gallon with Parent Isotope in Equilibrium with Daughters		Stable End Decay Product of Source	Curies of Parent per Curie of Source	Total Curies of Source per Curie or Parent
Parent Isotope	Radioactive Daughters			
Strontium 89	Yttrium 89	Y-89	1.0	1.0
Strontium 90	Yttrium 90	Zr-90	2.0	0.50
Yttrium 91		Zr-91	1.0	1.0
Zirconium 95	Niobium 95	Mo-95	2.0	0.50
Ruthenium 103	Rhodium 103m	Rh-103	2.0	0.50
Ruthenium 106	Rhodium 106	Pd-106	2.0	0.50
Cesium 134		Ba-134	1.0	1.0
Cesium 137	Barium 137m	Ba-137	1.9	0.52
Cerium 141		Pr-141	1.0	1.0
Cerium 144	Praesodymium 144	Nd-144	2.0	0.50

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TABLE 2SOURCE VOLUMES AND VESSEL DIMENSIONS

Volume	Equivalent Liter Volume	Vessel Dimensions		
		Inside Diameter in Inches	Tank Height or Length Inches	Ft. - In.
* 1 milliliter		0.4	0.4	
* 1 liter		4.0	4.9	
1 gallon	3.785	4.0	18.3	
* 10 liters	---	6.0	21.6	
15 gallons	56.77	14	24	2' 0"
55 gallons	208.2	22	34	2' 10"
150 gallons	567.7	30	49	4' 1"
500 gallons	1,892.5	45	73	6' 1"
2,000 gallons	7,570.	60	163	13' 6"
5,000 gallons	18,925	72	284	23' 6"
10,000 gallons	37,850	96	319	26' 6"
15,600 gallons	59,046	120	319	26' 6"

* Equivalent volume in gallons

1 milliliter = 2.64×10^{-4} gallons

1 liter = 0.264 gallons

10 liters = 2.64 gallons

TABLE 3SHIELDING ARRANGEMENTS

Thickness and Material of Shields				
Shield Arrangement No.	Adjacency to Source			Geometry of Shield
	First	Second	Third	
1	1/16" poly-ethylene			Cylindrical
2	1/2" plexi-glass			Cylindrical
3	1/8" iron			Cylindrical
4	1/4" iron			Cylindrical
5	1/2" iron			Cylindrical
6	1" iron			Cylindrical
7	2" iron			Cylindrical
8	1/4" iron	1/2" lead		Cylindrical
9	1/4" iron	1" lead		Cylindrical
10	1/4" iron	1" lead	1 Ft. water	Cylindrical
11	1/4" iron	2" lead		Cylindrical
12	1/2" iron	4" lead		Cylindrical
13	1/2" iron	8" lead		Cylindrical
14	1/4" iron	6" concrete		Slab
15	1/4" iron	12" concrete		Slab
16	1/4" iron	24" concrete		Slab
17	1/4" iron	48" concrete		Slab
18	1/4" iron	72" concrete		Slab

TABLE 4
COMPUTATION OF DOSE RATES (c)
DERIVATION OF REDUCTION FACTORS FOR DISTANCES GREATER THAN THREE FEET

DISTANCE FROM SIDE OF SOURCE	POINT (a) SOURCE	ONE (d) GALLON	15 (d) GALLONS	150 (e) GALLONS	500 (e) GALLONS	2,000 (e) GALLONS	10,000 (e) GALLONS
3 feet mr/hr Red F.	1.0	5.49×10^3 1.0	3.34×10^3 1.0	2.04×10^4 1.0	1.0	6.15×10^4 1.0	7.68×10^4 1.0
6 feet (b) mr/hr Red F.	3.0×10^{-1}	3.1×10^{-1}	3.5×10^{-1}	4.2×10^{-1}	5.0×10^{-1}	5.4×10^{-1}	7.0×10^{-1}
10 feet mr/hr Red F.	9.0×10^{-2}	5.33×10^2 3.7×10^{-2}	3.75×10^2 0.11	2.91×10^3 0.14	0.17	1.61×10^4 0.38	3.02×10^4 0.39
20 feet (b) mr/hr Red F.	2.2×10^{-2}	2.5×10^{-2}	2.8×10^{-2}	4.0×10^{-2}	5.0×10^{-2}	5.17×10^3 8.4×10^{-2}	1.6×10^{-1}
30 feet mr/hr Red F.	1.0×10^{-2}	6.0×10^1 1.1×10^{-2}	4.4×10^1 1.3×10^{-2}	3.5×10^2 1.7×10^{-2}	2.3×10^{-2}	2.50×10^3 4.1×10^{-2}	6.17×10^3 8.0×10^2
40 feet (b) mr/hr Red F.	5.6×10^{-3}	6.2×10^{-3}	7.3×10^{-3}	1.0×10^{-2}	1.3×10^{-2}	1.4×10^3 2.3×10^{-2}	3.4×10^2
50 feet mr/hr Red F.	3.6×10^{-3}	2.1×10^1 3.9×10^{-2}	1.6×10^1 4.7×10^{-3}	1.3×10^2 6.2×10^{-3}	8.3×10^{-3}	9.15×10^2 1.5×10^{-2}	2.42×10^3 3.1×10^{-2}

- (a) Calculated from Inverse Square
 (b) Interpolated from Figure 1
 (c) ZrNb^{95} used as source as shown for volumes
 (d) 10,000 curie total source
 (e) 1,000 curies/gallon

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FIGURE 1. Distances Greater Than 3 ft Versus Reduction in Dose Rate for Varying Volumes

FIGURE 2. Reduction in Dose Rate Versus Volume of Source for Varying Distances from Side of Source

TABLE 5
EMPIRICAL RADIATION DATA FOR FIGURE 3
OF
DOSE RATES AT DISTANCES OF LESS THAN 3 FEET

Curve No.	1		2		3		4		5	
Data:										
Vessel-----	Tank 1		Drum		Bottle		Bottle		Jar	
Dia. x Length-----	4' dia x 25'		18" dia x 5'		6" dia x 12"		4" dia x 12"		4" dia x 2"	
Reading Date-----	6-7-65		6-30-67		1-22-68		3-8-67		3-17-67	
Reading By-----	Moulthrop		Moulthrop		Moulthrop		Moulthrop		Moulthrop	
Reference-----	HWN-2081 Page 122		ISO-N-106 Page 107		ARH-N-78 Page 3		ISO-N-70 Page 69		ISO-N-70 Pages 80-81	
Distance of Reading in Inches From Side of Source	C.P. Reading in Mr/hr	Increase Factor above the 3 ft. Value	C.P. Reading in Mr/hr	Increase Factor above the 3 ft. Value	C.P. Reading in Mr/hr	Increase Factor above the 3 ft. Value	C.P. Reading in Mr/hr	Increase Factor above the 3 ft. Value	C.P. Reading in Mr/hr	Increase Factor above the 3 ft. Value
2	850	5.7	90	10.0	150	43.			800	114.
4									280	40.
6	500	2.95			42	12.	470	24.7	150	21.
9									80	11.4
12	310	1.9	31	3.4	18	5.1	130	6.8	50	7.1
18					10	2.9	60	3.1	28	4.0
24	220	1.3	17	1.9	7	2.0	38	2.0	16.5	2.3
30					5	1.6	27	1.4	11.0	1.5
36	170	1.0	9	1.0	3.5	1.0	19	1.0	7.0	1.0

Legend:

- Curve 1 - 4 ft diam x 25 ft long tank
- Curve 2 - 18 in. diam x 5 ft high drum
- Curve 3 - 6 in. diam x 12 in. high bottle
- Curve 4 - 4 in. diam x 12 in. high bottle
- Curve 5 - 4 in. diam x 2 in. high jar
- Curve 6 - Inverse square for pt. source

FIGURE 3. Distances Less Than 3 ft Versus Increase in Dose Rate for Varying Volumes

FIGURE 4. Unshielded* Dose Rates at 3 ft From Side of the Source Versus Source Volume for Individual Sources (* 1/16" Polyethylene Used As Minimum Shield)

FIGURE 5. *Shielded Dose Rates for 1 in. of Lead Plus 1/4 in. Iron*

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE

	** Sr ⁸⁹ (one curie per gal.)				
			1/4" Iron Plus		
	<u>1/16" Polyethylene</u>	<u>1/2" Iron</u>	<u>1" Lead</u>	<u>24" Concrete</u>	
	3 Feet	*10 Feet			
1 m-liter	7.5×10^{-2}	7.5×10^{-3}	1.8×10^{-3}	1.5×10^{-5}	3.9×10^{-9}
1 liter	3.0×10^1	33×10^0	1.1	8.1×10^{-3}	1.8×10^{-6}
10 liters	2.3×10^2	2.8×10^3	8.5	5.9×10^{-2}	1.2×10^{-5}
15 gallons	8.7×10^2	1.3×10^2	2.6×10^1	1.8×10^{-1}	3.6×10^{-3}
55 gallons	6.8×10^3	2.9×10^2	5.6×10^1	3.6×10^{-1}	7.0×10^{-3}
500 gallons	6.8×10^3	1.4×10^3	1.6×10^2	9.1×10^{-1}	1.7×10^{-4}
2,000 gallons	8.6×10^3	3.9×10^3	2.3×10^2	1.2	2.4×10^{-4}
10,000 gallons	1.7×10^4	6.5×10^3	3.4×10^2	1.7	4.9×10^{-4}
15,600 gallons	2.0×10^4	8.0×10^3	3.6×10^2	1.8	5.2×10^{-4}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	1.1×10^2	4.1×10^3	1.7×10^4
1/2" Plexiglass	7.2×10^1	1.7×10^3	6.1×10^3
1/8" Iron	2.9×10^1	7.2×10^2	6.1×10^3
1/4" Iron	1.9×10^1	4.7×10^2	1.5×10^3
1/2" Iron	4.1	9.4×10^1	2.7×10^2
1" Iron	1.7	3.6×10^1	9.5×10^1
2" Iron	3.7×10^{-1}	6.9	1.6×10^1
1/4" Iron, 1/2" Lead	1.4×10^{-1}	2.9	7.4
1/4" Iron, 1" Lead	2.9×10^{-2}	5.8×10^{-1}	1.4
1/4" Iron, 1" Lead, 1' H ₂ O	2.5×10^{-2}	4.5×10^{-1}	9.1×10^{-1}
1/2" Iron, 2" Lead	1.9×10^{-3}	3.2×10^{-2}	6.7×10^{-2}
1/2" Iron, 4" Lead	2.6×10^{-5}	3.6×10^{-4}	6.6×10^{-4}

* Indicates dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 6 (continued)
Sr⁸⁹

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	1.2×10^{-8}	1.3×10^{-7}	2.2×10^{-7}
*1/16" Polyethylene	1.3×10^{-1}	6.1×10^2	3.0×10^3
*1/4" Iron, 6" Concrete	5.6×10^{-2}	9.0×10^{-1}	6.3×10^0
*1/4" Iron, 12" Concrete	2.8×10^{-3}	5.1×10^{-1}	2.2×10^{-1}
*1/4" Iron, 24" Concrete	7.7×10^{-6}	1.2×10^{-5}	4.5×10^{-4}
*1/4" Iron, 48" Concrete	2.1×10^{-10}	6.2×10^{-9}	1.9×10^{-8}
*1/4" Iron, 72" Concrete	1.9×10^{-14}	5.5×10^{-13}	1.4×10^{-12}

* Indicates dose rate is at 10 feet from side of source

FIGURE 6A. Source Concentration: 1 Curie per Gallon

FIGURE 6B. Source Concentration: 1 Curie per Gallon

FIGURE 6C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE**Sr⁹⁰ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	7.6×10^{-2}	7.6×10^{-3}	2.9×10^{-3}	6.9×10^{-5}	2.0×10^{-8}
1 liter	3.1×10^1	3.4×10^0	1.9	4.1×10^{-2}	1.0×10^{-6}
10 liters	2.5×10^2	2.7×10^1	1.4×10^1	3.1×10^{-1}	7.7×10^{-5}
15 gallons	9.2×10^2	1.3×10^2	4.5×10^1	9.8×10^{-1}	2.5×10^{-4}
55 gallons	2.2×10^3	2.9×10^2	9.9×10^1	2.1	5.0×10^{-4}
500 gallons	7.2×10^3	1.4×10^3	2.9×10^2	5.5	1.3×10^{-3}
2,000 gallons	9.3×10^3	2.3×10^3	4.2×10^2	7.2	1.8×10^{-3}
10,000 gallons	1.8×10^4	6.7×10^3	6.3×10^2	1.1×10^1	4.9×10^{-3}
15,600 gallons	2.1×10^4	8.4×10^3	6.7×10^2	1.1×10^1	5.2×10^{-3}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16 Polyethylene	1.1×10^2	4.3×10^3	1.8×10^4
1/2" Plexiglass	7.8×10^1	2.0×10^3	6.9×10^3
1/8" Iron	3.6×10^1	9.5×10^2	3.1×10^3
1/4" Iron	2.6×10^1	6.9×10^2	2.2×10^3
1/2" Iron	6.8	1.7×10^2	5.0×10^2
1" Iron	3.1	7.3×10^1	2.0×10^2
2" Iron	$82. \times 10^{-1}$	1.7×10^1	4.2×10^1
1/4" Iron, 1/2" Lead	4.8×10^{-1}	1.2×10^1	3.2×10^1
1/4" Iron, 1" Lead	1.5×10^1	3.4	8.5
1/4" Iron, 1" Lead, 1' H ₂ O	1.0×10^{-2}	2.2	4.6
1/2" Iron, 2" Lead	1.7×10^{-2}	3.4×10^{-1}	7.4×10^{-1}
1/2" Iron, 4" Lead	5.7×10^{-4}	9.7×10^{-3}	1.9×10^{-2}

* Indicates dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 7 (continued)
Sr⁹⁰

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	1.6×10^{-6}	2.2×10^{-5}	3.9×10^{-5}
*1/16" Polyethylene	1.3×10^1	7.8×10^2	6.3×10^3
*1/4" Iron, 1" Concrete	1.1×10^{-1}	2.7×10^0	14×10^1
*1/4" Iron, 12" Concrete	7.3×10^3	1.5×10^{-1}	7.0×10^{-1}
*1/4" Iron, 24" Concrete	4.4×10^{-5}	8.7×10^{-4}	4.2×10^{-3}
*1/4" Iron, 48" Concrete	4.7×10^{-9}	2.1×10^{-7}	
*1/4" Iron, 72" Concrete	2.8×10^{-12}	1.0×10^{-10}	

* Indicates dose rate is at 10 feet from side of source

FIGURE 7A. Source Concentration: 1 Curie per Gallon

FIGURE 7B. Source Concentration: 1 Curie per Gallon

FIGURE 7C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE**Y⁹¹ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	6.0×10^{-2}	6.0×10^{-3}	1.7×10^{-3}	1.3×10^{-1}	4.0×10^{-8}
1 liter	2.4×10^1	2.6×10^0	1.1	8.2×10^{-2}	4.7×10^{-5}
10 liters	1.8×10^2	2.2×10^1	8.6	6.3×10^{-1}	1.6×10^{-4}
15 gallons	6.9×10^2	9.0×10^1	2.9×10^1	2.1	5.2×10^{-4}
55 gallons	1.7×10^3	2.4×10^2	6.4×10^1	4.0	1.0×10^{-4}
500 gallons	5.4×10^3	8.0×10^2	1.9×10^2	1.2×10^1	3.0×10^{-3}
2,000 gallons	6.9×10^3	1.7×10^3	2.9×10^2	1.7×10^1	4.0×10^{-3}
10,000 gallons	1.3×10^4	4.9×10^3	4.5×10^2	2.4×10^1	8.0×10^{-3}
15,600 gallons	1.6×10^4	6.1×10^3	4.7×10^2	2.6×10^1	8.3×10^{-3}
		<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>	
1/16" Polyethylene		8.5×10^1	3.3×10^3	1.4×10^4	
1/2" Plexiglass		5.7×10^1	1.4×10^3	4.9×10^3	
1/8" Iron		2.1×10^1	5.5×10^2	1.8×10^3	
1/4" Iron		1.4×10^1	3.8×10^2	1.2×10^3	
1/2" Iron		4.0	1.1×10^2	3.5×10^2	
1" Iron		2.1	$5/6 \times 10^1$	1.7×10^2	
2" Iron		7.3×10^{-1}	1.9×10^1	4.8×10^1	
1/4" Iron, 1/2" Lead		6.7×10^{-1}	1.9×10^1	5.5×10^1	
1/4" Iron, 1" Lead		2.9×10^{-1}	7.6	1.9×10^1	
1/4" Iron, 1" Lead, 1' H ₂ O		1.7×10^{-1}	4.0	8.9	
1/2" Iron, 2" Lead		4.8×10^{-2}	9.8×10^{-1}	2.1	
1/2" Iron, 4" Lead		1.7×10^{-3}	2.7×10^{-2}	5.2×10^{-2}	
1/2" Iron, 8" Lead		2.1×10^{-6}	2.4×10^{-5}	4.2×10^{-5}	

*Indicated dose rate is at 10 feet from side of source

**Exact source is as defined in Table 1

TABLE 8 (continued)
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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
*1/16" Polyethylene	1.0×10^0	4.9×10^2	4.9×10^3
*1/4" Iron, 6" Concrete	8.0×10^{-2}	2.3×10^0	1.2×10^1
*1/4" Iron, 12" Concrete	8.4×10^{-3}	2.1×10^{-1}	9.8×10^{-1}
*1/4" Iron, 24" Concrete	9.1×10^{-5}	1.8×10^{-3}	7.3×10^{-3}
*1/4" Iron, 48" Concrete	8.5×10^{-9}	2.8×10^{-7}	8.6×10^{-7}
*1/4" Iron, 72" Concrete	1.2×10^{-12}	3.6×10^{-11}	9.3×10^{-11}

*Indicated dose rate is at 10 feet from side of source

FIGURE 8A. Source Concentration: 1 Curie per Gallon

FIGURE 8B. Source Concentration: 1 Curie per Gallon

FIGURE 8C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE**Zr⁹⁵ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1" Lead</u>	<u>1/4" Iron Plus *24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	1.5×10^{-1}	1.5×10^{-2}	1.2×10^{-1}	1.5×10^{-2}	1.9×10^{-6}
1 liter	1.4×10^2	1.5×10^1	8.9×10^1	8.7	8.9×10^{-4}
10 liters	1.2×10^3	1.4×10^2	7.3×10^2	6.4×10^1	6.5×10^{-3}
15 gallons	5.3×10^3	6.9×10^2	2.7×10^3	1.9×10^2	2.0×10^{-2}
55 gallons	1.3×10^4	1.8×10^3	6.1×10^3	4.0×10^2	3.8×10^{-2}
500 gallons	4.3×10^4	8.6×10^3	1.9×10^4	1.0×10^3	9.2×10^{-2}
2,000 gallons	7.0×10^4	1.7×10^4	2.9×10^4	1.3×10^3	1.3×10^{-1}
10,000 gallons	1.2×10^5	4.5×10^4	4.5×10^4	1.9×10^3	2.7×10^{-1}
15,600 gallons	1.3×10^5	5.2×10^4	4.8×10^4	2.0×10^3	2.8×10^{-1}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	5.4×10^2	2.5×10^4	10.0×10^4
1/2" Plexiglass	5.2×10^2	2.2×10^4	8.6×10^4
1/8" Iron	5.1×10^2	2.1×10^4	8.2×10^4
1/4" Iron	5.0×10^2	1.9×10^4	7.2×10^4
1/2" Iron	3.3×10^2	1.1×10^4	3.6×10^4
1" Iron	2.2×10^2	6.5×10^3	1.9×10^4
2" Iron	9.3×10^1	2.2×10^3	5.5×10^3
1/4" Iron, 1/2" Lead	9.7×10^1	2.3×10^3	6.2×10^3
1/4" Iron, 1" Lead	3.1×10^1	6.5×10^2	1.5×10^3
1/4" Iron, 1" Lead, 1' H ₂ O	2.1×10^1	3.9×10^2	8.2×10^2
1/2" Iron, 2" Lead	2.3	3.6×10^1	7.3×10^1
1/2" Iron, 4" Lead	1.8×10^{-2}	2.1×10^{-1}	3.8×10^{-1}

* Indicated dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 9 (continued)
Zr⁹⁵

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	1.1×10^{-6}	9.4×10^{-6}	1.6×10^{-5}
*1/16" Polyethylene	6.4×10^1	3.7×10^3	3.5×10^4
*1/4" Iron, 6" Concrete	8.5×10^0	2.4×10^2	1.3×10^3
*1/4" Iron, 12" Concrete	7.9×10^{-1}	1.8×10^1	7.7×10^1
*1/4" Iron, 24" Concrete	4.0×10^{-3}	6.4×10^2	2.4×10^{-1}
*1/4" Iron, 48" Concrete	5.9×10^{-8}	1.6×10^{-6}	4.5×10^{-6}
*1/4" Iron, 72" Concrete	1.3×10^{-12}	8.3×10^{-11}	8.0×10^{-11}

* Indicated dose rate is at 10 feet from side of source

FIGURE 9A. Source Concentration: 1 Curie per Gallon

FIGURE 9B. Source Concentration: 1 Curie per Gallon

FIGURE 9C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE**Ru¹⁰³ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	5.5×10^{-2}	5.5×10^{-3}	3.2×10^{-2}	3.3×10^{-4}	1.5×10^{-7}
1 liter	6.0×10^1	6.6×10^0	2.3×10^1	1.6×10^{-1}	6.2×10^{-5}
10 liters	5.4×10^2	6.5×10^1	1.8×10^2	1.0	4.2×10^{-4}
15 gallons	2.2×10^3	2.9×10^2	6.0×10^2	2.8	1.2×10^{-3}
55 gallons	5.1×10^3	7.1×10^2	1.3×10^3	5.5	2.1×10^{-3}
500 gallons	1.7×10^4	3.4×10^3	3.9×10^3	1.2×10^1	5.0×10^{-1}
2,000 gallons	2.6×10^4	6.5×10^{-1}	5.7×10^3	1.5×10^1	1.0×10^{-3}
10,000 gallons	4.5×10^4	2.3×10^4	8.7×10^3	2.2×10^1	1.4×10^{-2}
15,600 gallons	4.7×10^4	1.9×10^4	9.2×10^3	2.3×10^1	1.5×10^{-2}
		<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>	
1/16" Polyethylene		2.2×10^2	9.8×10^3	3.7×10^4	
1/2" Plexiglass		2.2×10^2	8.6×10^3	3.2×10^4	
1/8" Iron		2.2×10^2	8.1×10^3	2.9×10^4	
1/4" Iron		2.2×10^2	7.4×10^3	2.6×10^4	
1/2" Iron		8.3×10^1	2.2×10^3	6.9×10^3	
1" Iron		4.8×10^1	1.1×10^3	3.0×10^3	
2" Iron		1.4×10^1	2.6×10^2	5.9×10^2	
1/4" Iron, 1/2" Lead		5.6	1.0×10^2	2.4×10^2	
1/4" Iron, 1" Lead		5.5×10^{-1}	8.5	1.8×10^1	
1/4" Iron, 1" Lead, 1' H ₂ O		8.3×10^{-1}	1.2×10^1	2.4×10^1	
1/2" Iron, 2" Lead		5.5×10^{-3}	6.8×10^{-2}	1.3×10^{-1}	
1/2" Iron, 4" Lead		2.8×10^{-6}	2.7×10^{-5}	4.7×10^{-5}	

* Indicated dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 10 (continued)
Ru¹⁰³

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	1.7×10^{-12}	1.1×10^{-11}	1.8×10^{-11}
*1/16" Polyethylene	2.6×10^1	1.5×10^3	1.3×10^4
*1/4" Iron, 6" Concrete	2.2×10^0	5.0×10^1	2.5×10^2
*1/4" Iron, 12" Concrete	1.3×10^{-1}	2.4×10^0	1.0×10^1
*1/4" Iron, 24" Concrete	2.7×10^{-4}	3.6×10^{-3}	1.4×10^{-2}
*1/4" Iron, 48" Concrete	7.9×10^{-10}	1.8×10^{-8}	4.9×10^{-8}
*1/4" Iron, 72" Concrete	3.8×10^{-15}	7.9×10^{-14}	1.9×10^{-13}

* Indicated dose rate is at 10 feet from side of source

FIGURE 10A. Source Concentration: 1 Curie per Gallon

FIGURE 10B. Source Concentration: 1 Curie per Gallon

FIGURE 10C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE** Ru¹⁰⁶ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	1.3×10^{-1}	1.3×10^{-2}	2.2×10^{-2}	1.2×10^{-3}	5.6×10^{-7}
1 liter	6.9×10^1	7.6×10^0	1.5×10^1	7.5×10^{-1}	3.1×10^{-4}
10 liters	5.8×10^2	7.0×10^1	1.2×10^2	5.7	2.4×10^{-3}
15 gallons	2.3×10^3	3.0×10^2	4.2×10^2	1.9×10^1	8.4×10^{-3}
55 gallons	5.4×10^3	7.5×10^2	9.4×10^2	3.2×10^1	1.7×10^{-2}
500 gallons	1.8×10^4	3.6×10^3	2.9×10^3	1.1×10^2	5.2×10^{-2}
2,000 gallons	2.5×10^4	6.2×10^3	4.3×10^3	1.5×10^2	7.5×10^{-2}
10,000 gallons	4.6×10^4	1.7×10^4	6.6×10^3	2.2×10^2	1.6×10^{-1}
15,600 gallons	5.2×10^4	2.1×10^4	7.0×10^3	2.3×10^2	1.7×10^{-1}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	2.5×10^2	1.0×10^4	4.0×10^4
1/2" Plexiglass	2.1×10^2	6.7×10^3	2.5×10^4
1/8" Iron	1.5×10^2	5.2×10^3	1.9×10^4
1/4" Iron	1.4×10^2	4.5×10^3	1.6×10^4
1/2" Iron	5.5×10^1	1.6×10^3	5.2×10^3
1" Iron	3.3×10^1	8.8×10^2	2.5×10^3
2" Iron	1.1×10^1	2.6×10^2	6.6×10^2
1/4" Iron, 1/2" Lead	8.3	2.1×10^2	5.8×10^2
1/4" Iron, 1" Lead	2.7	6.7×10^1	1.7×10^2
1/4" Iron, 1" Lead, 1' H ₂ O	1.9	4.3×10^1	9.5×10^1
1/4" Iron, 2" Lead	3.8×10^{-1}	8.6	1.9×10^1
1/2" Iron, 4" Lead	2.0×10^{-2}	4.1×10	8.4×10^{-1}

* Indicated dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 11 (continued)
Ru¹⁰⁶

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	1.4×10^{-4}	2.4×10^{-3}	4.4×10^{-3}
*1/16" Polyethylene	3.0×10^1	1.5×10^3	1.4×10^4
*1/4" Iron, 6" Concrete	1.4×10^0	3.7×10^1	2.0×10^2
*1/4" Iron, 12" Concrete	1.2×10^{-1}	2.8×10^0	1.3×10^1
*1/4" Iron, 24" Concrete	1.3×10^{-3}	3.1×10^{-2}	1.3×10^{-1}
*1/4" Iron, 48" Concrete	9.2×10^{-7}	4.2×10^{-5}	1.5×10^{-4}
*1/4" Iron, 72" Concrete	1.9×10^{-9}	8.6×10^{-8}	2.7×10^{-7}

* Indicated dose rate is at 10 feet from side of source

FIGURE 11A. Source Concentration: 1 Curie per Gallon

FIGURE 11B. Source Concentration: 1 Curie per Gallon

FIGURE 11C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE** Cs¹³⁴ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	3.3×10^{-1}	3.3×10^{-2}	2.5×10^{-1}	2.1×10^{-2}	3.7×10^{-6}
1 liter	3.1×10^2	3.4×10^1	1.8×10^2	1.2×10^1	1.9×10^{-3}
10 liters	2.8×10^3	3.1×10^2	1.5×10^3	9.0×10^1	1.3×10^{-2}
15 gallons	1.2×10^4	1.4×10^3	5.4×10^3	2.8×10^2	4.3×10^{-2}
55 gallons	2.9×10^4	3.8×10^3	1.2×10^4	5.8×10^2	8.5×10^{-2}
500 gallons	9.9×10^4	2.0×10^4	3.8×10^4	1.5×10^3	2.2×10^{-1}
2,000 gallons	1.6×10^5	4.0×10^4	5.8×10^4	1.9×10^3	3.0×10^{-1}
10,000 gallons	2.7×10^5	1.0×10^5	9.0×10^4	2.8×10^3	6.4×10^{-1}
15,600 gallons	2.9×10^5	1.1×10^5	9.5×10^4	3.0×10^3	

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	1.3×10^3	5.8×10^4	2.3×10^5
1/2" Plexiglass	1.3×10^3	5.1×10^4	2.0×10^5
1/8" Iron	1.2×10^3	4.8×10^4	1.9×10^5
1/4" Iron	1.1×10^3	4.4×10^4	1.6×10^5
1/2" Iron	6.7×10^2	2.1×10^4	7.1×10^4
1" Iron	4.5×10^2	1.3×10^4	3.7×10^4
2" Iron	1.8×10^2	4.2×10^3	1.0×10^4
1/4" Iron, 1/2" Lead	1.5×10^2	3.6×10^3	9.5×10^3
1/4" Iron, 1" Lead	4.4×10^1	9.4×10^2	2.3×10^3
1/2" Iron, 1" Lead, 1' H ₂ O	3.3×10^1	6.5×10^2	1.4×10^3
1/2" Iron, 2" Lead	3.6	6.7×10^1	1.4×10^2
1/2" Iron, 4" Lead	8.6×10^{-2}	1.5	2.9

* Indicated dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 12 (continued)
Cs134

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	2.0×10^{-1}	2.8×10^{-3}	5.0×10^{-3}
*1/16" Polyethylene	1.5×10^2	8.7×10^3	8.0×10^4
*1/4" Iron, 6" Concrete	1.7×10^1	4.6×10^2	2.5×10^3
*1/4" Iron, 12" Concrete	1.4×10^0	3.1×10^1	1.4×10^2
*1/4" Iron, 24" Concrete	7.9×10^{-3}	1.9×10^{-1}	6.0×10^{-1}
*1/4" Iron, 48" Concrete	6.1×10^{-7}	2.3×10^{-5}	7.3×10^{-5}
*1/4" Iron, 72" Concrete	1.6×10^{-10}	5.7×10^{-9}	1.6×10^{-8}

* Indicated dose rate is at 10 feet from side of source

FIGURE 12A. Source Concentration: 1 Curie per Gallon

FIGURE 12B. Source Concentration: 1 Curie per Gallon

FIGURE 12C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE**Cs¹³⁷ (one curie per gal.)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	6.5×10^{-2}	6.5×10^{-3}	4.2×10^{-2}	1.4×10^{-3}	2.3×10^{-7}
1 liter	6.0×10^1	6.6×10^0	3.1×10^1	7.1×10^{-1}	1.0×10^{-5}
10 liters	5.4×10^2	6.5×10^1	2.5×10^2	5.0	7.0×10^{-4}
15 gallons	2.2×10^3	2.9×10^2	8.2×10^2	1.3×10^1	1.9×10^{-3}
55 gallons	5.1×10^3	8.1×10^2	1.8×10^3	2.6×10^1	3.5×10^{-3}
500 gallons	1.7×10^4	3.4×10^3	5.6×10^3	6.1×10^1	8.6×10^{-1}
2,000 gallons	2.8×10^4	7.0×10^3	8.5×10^3	7.5×10^1	1.2×10^{-1}
10,000 gallons	4.8×10^4	1.8×10^4	1.3×10^4	1.1×10^2	2.4×10^{-2}
15,600 gallons	5.1×10^4	2.0×10^4	1.4×10^4	1.2×10^2	2.6×10^{-2}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	2.2×10^2	1.0×10^4	4.1×10^4
1/2" Plexiglass	2.3×10^2	9.5×10^3	3.7×10^4
1/8" Iron	2.2×10^2	9.2×10^3	3.5×10^4
1/4" Iron	2.2×10^2	8.5×10^3	3.1×10^4
1/2" Iron	1.2×10^2	3.6×10^3	1.1×10^4
1" Iron	7.4×10^1	2.0×10^3	5.7×10^3
2" Iron	2.7×10^1	5.9×10^2	1.4×10^3
1/4" Iron, 1/2" Lead	1.5×10^1	3.2×10^2	7.9×10^2
1/4" Iron, 1" Lead	2.6	4.5×10^1	9.9×10^1
1/4" Iron, 1" Lead, 1' H ₂ O	3.2	5.5×10^1	1.1×10^2
1/2" Iron, 2" Lead	5.1×10^{-2}	6.7×10^{-1}	1.3
1/2" Iron, 4" Lead	3.5×10^{-5}	3.4×10^{-4}	5.9×10^{-4}

*Indicated dose rate is at 10 feet from side of source

**Exact source is as defined in Table 1

TABLE 13 (continued)
Cs¹³⁷

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	3.0×10^{-11}	2.2×10^{-10}	3.8×10^{-10}
*1/16" Polyethylene	2.6×10^1	1.5×10^3	1.4×10^4
*1/4" Iron, 6" Concrete	2.8×10^0	7.2×10^1	3.8×10^2
*1/4" Iron, 12" Concrete	1.8×10^{-1}	3.7×10^0	1.6×10^0
*1/4" Iron, 24" Concrete	4.6×10^{-4}	6.6×10^3	2.5×10^{-2}
*1/4" Iron, 48" Concrete	1.8×10^{-9}	1.5×10^{-8}	1.2×10^{-7}
*1/4" Iron, 72" Concrete	1.2×10^{-14}	2.7×10^{-13}	6.4×10^{-13}

* Indicated dose rate is at 10 feet from side of source

FIGURE 13A. Source Concentration: 1 Curie per Gallon

FIGURE 13B. Source Concentration: 1 Curie per Gallon

FIGURE 13C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE**Ce¹⁴¹ (one curie per gal)

	<u>1/16" Polyethylene</u>	<u>1/2" Iron</u>	<u>1/4" Iron Plus 1" Lead</u>	<u>*24" Concrete</u>
	3 Feet	10 Feet		
1 m-liter	3.4×10^2	3.4×10^{-3}	6.6×10^{-3}	1.6×10^{-9}
1 liter	2.7×10^1	3.0×10^0	3.5	6.9×10^{-7}
10 liters	2.2×10^2	2.6×10^1	2.5×10^1	4.4×10^{-6}
15 gallons	7.7×10^2	1.0×10^2	6.9×10^1	1.1×10^{-5}
55 gallons	1.7×10^3	2.4×10^2	1.4×10^2	2.2×10^{-5}
500 gallons	5.3×10^3	1.0×10^3	3.7×10^2	4.6×10^{-5}
2,000 gallons	7.4×10^3	1.8×10^3	5.1×10^2	5.6×10^{-5}
10,000 gallons	1.4×10^4	5.3×10^3	7.3×10^2	8.0×10^{-5}
15,600 gallons	1.4×10^4	3.6×10^3	7.9×10^2	8.5×10^{-5}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	9.7×10^1	2.9×10^3	1.0×10^4
1/2" Plexiglass	9.1×10^1	2.3×10^3	7.8×10^3
1/8" Iron	7.9×10^1	1.9×10^3	6.1×10^3
1/4" Iron	6.4×10^1	1.4×10^3	4.1×10^3
1/2" Iron	1.3×10^1	2.3×10^2	6.1×10^2
1" Iron	2.6	4.0×10^1	9.1×10^1
2" Iron	8.7×10^{-2}	1.0	2.1
1/4" Iron, 1/2" Lead	2.8×10^{-5}	1.2×10^{-3}	2.6×10^{-3}
1/4" Iron, 1" Lead	2.4×10^{-6}	3.3×10^{-5}	6.7×10^{-5}
1/4" Iron, 1" Lead, 1' H ₂ O	4.6×10^{-6}	6.0×10^{-5}	6.7×10^{-5}
1/2" Iron, 2" Lead	7.8×10^{-9}	8.2×10^{-8}	1.5×10^{-7}
1/2" Iron, 4" Lead	3.2×10^{-13}	2.4×10^{-12}	4.1×10^{-12}

* Indicated dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>50,000 Gallon</u>
1/2" Iron, 8" Lead	7.7×10^{-22}	3.4×10^{-21}	6.7×10^{-21}
*1/16" Polyethylene	1.6×10^1	4.3×10^2	3.5×10^3
*1/4" Iron, 6" Concrete	2.4×10^{-2}	3.4×10^{-1}	1.5×10^{-0}
*1/4" Iron, 12" Concrete	6.6×10^{-5}	7.3×10^{-4}	3.0×10^{-3}
*1/4" Iron, 24" Concrete	7.2×10^{-9}	8.4×10^{-8}	3.1×10^{-7}
*1/4" Iron, 48" Concrete	6.8×10^{-15}	1.4×10^{-13}	3.8×10^{-13}
*1/4" Iron, 72" Concrete	1.9×10^{-20}	3.7×10^{-19}	8.7×10^{-19}

* Indicated dose rate is at 10 feet from side of source

FIGURE 14A. Source Concentration: 1 Curie per Gallon

FIGURE 14B. Source Concentration: 1 Curie per Gallon

FIGURE 14C. Source Concentration: 1 Curie per Gallon

DOSE RATE IN MR/HR AT 3 FEET* FROM SIDE OF SOURCE** Ce^{144} (one curie per gal)

	<u>1/16" Polyethylene</u>		<u>1/2" Iron</u>	<u>1" Lead</u>	<u>1/4" Iron Plus *24" Concrete</u>
	3 Feet	10 Feet			
1 m-liter	1.3×10^{-1}		1.4×10^{-2}	1.6×10^{-3}	2.0×10^{-6}
1 liter	6.4×10^1	7.0×10^0	9.3	1.1	1.2×10^{-3}
10 liters	5.2×10^2	5.7×10^1	7.4×10^1	8.4	1.0×10^{-2}
15 gallons	1.6×10^3	1.9×10^2	2.1×10^2	2.5×10^1	3.0×10^{-2}
55 gallons	3.8×10^3	4.9×10^2	4.7×10^2	5.6×10^1	6.4×10^{-2}
500 gallons	1.2×10^4	2.4×10^3	1.5×10^3	1.7×10^2	1.9×10^{-1}
2,000 gallons	1.7×10^4	4.2×10^3	2.3×10^3	2.4×10^2	4.9×10^{-1}
10,000 gallons	3.2×10^4	1.2×10^4	3.6×10^3	3.5×10^2	
15,600 gallons	3.7×10^4	1.5×10^4	3.8×10^3	3.7×10^2	6.4×10^{-1}

	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/16" Polyethylene	1.9×10^2	7.2×10^3	2.9×10^4
1/2" Plexiglass	1.4×10^2	4.1×10^3	1.5×10^4
1/8" Iron	9.1×10^1	2.8×10^3	1.0×10^4
1/4" Iron	7.4×10^1	2.3×10^3	7.8×10^3
1/2" Iron	2.7×10^1	8.4×10^2	2.8×10^3
1" Iron	1.5×10^1	4.8×10^2	2.8×10^3
2" Iron	6.3	1.9×10^2	5.2×10^2
1/4" Iron, 1/2" Lead	6.1	2.0×10^2	6.4×10^2
1/4" Iron, 1" Lead	3.1	9.7×10^1	2.8×10^2
1/4" Iron, 1" Lead, 1' H_2O	2.1	6.0×10^1	1.5×10^2
1/2" Iron, 2" Lead	8.0×10^{-1}	2.2×10^1	5.4×10^1
1/2" Iron, 4" Lead	8.0×10^{-2}	1.8	3.7

* Indicated dose rate is at 10 feet from side of source

** Exact source is as defined in Table 1

TABLE 15 (continued)
 Ce^{144}

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	<u>1 Gallon</u>	<u>150 Gallon</u>	<u>5,000 Gallon</u>
1/2" Iron, 8" Lead	7.9×10^{-4}	1.3×10^{-2}	2.4×10^{-2}
*1/16" Polyethylene	2.3×10^1	8.0×10^2	1.0×10^4
*1/4" Iron, 6" Concrete	7.1×10^{-1}	2.4×10^1	1.5×10^2
*1/4" Iron, 12" Concrete	1.2×10^{-2}	3.7×10^0	2.0×10^1
*1/4" Iron, 24" Concrete	4.2×10^{-3}	1.2×10^{-1}	4.9×10^{-1}
*1/4" Iron, 48" Concrete	4.5×10^{-6}	2.0×10^{-4}	7.0×10^{-4}
*1/4" Iron, 72" Concrete	6.6×10^{-9}	2.7×10^{-7}	8.1×10^{-7}

* Indicated dose rate is at 10 feet from side of source

FIGURE 15A. Source Concentration: 1 Curie per Gallon

FIGURE 15B. Source Concentration: 1 Curie per Gallon

FIGURE 15C. Source Concentration: 1 Curie per Gallon

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