STAFF TECHNICAL POSITION

FUEL PROCESSING AND FABRICATION BRANCH

INTERIM LAND CLEANUP CRITERIA

FOR

DECOMMISSIONING URANIUM MILL SITES

May 1978

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BACKGROUND

Uranium milling operations involve the handling of large quantities of ore containing uranium and its daughter products in concentrations one hundred to one thousand times the concentrations of these radionuclides in the natural terrestrial environment. Therefore, these milling operations have the potential for contaminating large areas of land both on and off the mill site. This contamination can result primarily from airborne dispersal of ore and tailings during the handling and storage of these materials.

Studies at inactive mill sites have indicated widespread contamination of these sites, extending in some cases over several hundreds of acres. Similar situations are expected to exist at some of the presently active mill sites. In order to minimize any further land contamination from blowing ore or tailings, the uranium mill operators are now being required by NRC to control the dispersal of these materials during the milling operations. It is expected with the implementation of good control practices that land contamination at new uranium mill sites can be limited to areas in close proximity to the mill buildings, ore pads, and tailings areas.

The operators of uranium mills are required by NRC to submit a decommissioning plan for the mill site as a part of the license application. Since the decommissioning of a mill site will involve a cleanup of contaminated areas, it is necessary that these cleanup plans be included in the overall decommissioning plan. Therefore, in order to provide guidance to mill operators in developing these decommissioning plans and in estimating the costs associated with land cleanup, the NRC staff has developed the "Interim Land Cleanup Criteria for Uranium Mill Sites" presented below. These criteria are presented in terms of "Target Criteria" and "Alternative or Upper Limit Criteria."

The Target Criteria represent the objectives which the land cleanup efforts should strive to obtain and below which no additional cleanup is necessary. These criteria will be most applicable to recently licensed or new uranium mills where effective control measures should minimize the contamination of land. For these milling operations, the target criteria should provide one of the bench marks in judging the acceptability of contamination control practices.

The Alternative or Upper Limit Criteria represent not to be exceeded levels for sites where cleanup to the Target Criteria are found to be impracticable. These alternative criteria are meant to be applied primarily to older mill sites, where in the past, lack of good land control practices may have resulted in contamination levels which cannot practicably be reduced to the Target Criteria.

INTERIM LAND CLEANUP CRITERIA FOR URANIUM MILL SITES

These Interim Land Cleanup Criteria are presented in terms of limits on radon-222 flux and gamma dose-rate since these are the exposure pathways which contribute the highest doses and have the greatest health significance at a contaminated uranium mill site. No criteria are presented for other potential exposure pathways such as inhalation of resuspended particulates or ingestion of contaminated food grown on the site, since these pathways will contribute less significant doses than those pathways for which criteria are presented (see Table 1 and Appendices A-D). Limiting the potential exposures from inhalation of radon-222 daughters and external gamma-rays will also result in limitation of exposures from all other pathways to acceptable levels.

The interrelationship between radium-226 soil concentrations, radon-222 flux, and gamma dose-rates is a complex function of many factors including the distribution of radium-226 in soil with depth. Figure 1 shows the relationship between the gamma dose-rate and radium-226 in soil concentration as a function of depth. Figure 2 shows the relationship between the radon-222 flux and the radium-226 in soil concentration as a function of depth. As can be seen from these figures, the shallower the depth of contamination, the higher the radium-226 concentration in soil that is equivalent to the cleanup criteria. For example, for contamination distributed throughout the top 2.5 cm of soil, a radium-226 concentration of 15 pCi/g is equivalent to the target criteria of 5 μr/hr. For this same depth, a concentration of 130 pCi/g is equivalent to the target criteria for radon flux. Therefore, since no simple numerical criteria in terms of radium-226 concentration in soil is applicable, no attempt has been made to express these criteria directly in terms of radium-226 soil concentrations. However, it is expected that the implementation plans from these criteria would involve the development of an effective relationship between these criteria and radium-226 soil concentrations. The development of any such relationships of course would have to take into consideration the dependence of these relationships on the depth profile of radium-226 in soil.

Target Criteria

It should be the objective of a decommissioning program at a uranium mill site to reduce the radon-222 flux and gamma dose-rate above background to below the following Target Criteria:

1. The radon-222 flux (above background) at the soil-air interface should not exceed a flux equivalent to that which would result from a soil concentration of 3 pCi/g of radium-226 at infinite thickness (see note 3 below and Appendix A).
2. The gamma dose-rate in air one meter above the ground should not exceed five (5) microroentgens per hour (above background).

Notes

1. These criteria were developed with the expectation that the soil nearest the surface will contain the highest concentrations of contamination and that in general the soil concentrations will decrease with depth. These

criteria do not apply to tailings disposal or to any typ of waste burial. For mill sites where the contamination profile is significantly different from that described above, land cleanup criteria will need to be developed on a case-by-case basis.

2. Soil profile sampling or in-situ gamma ray measurements of boreholes should be made to define the profile and depth of contamination and to determine if any unsuspected subsurface contamination exists.
3. When the soil contamination profile is known to be similar to that described in note 1 above (i.e., the highest concentration near the surface), then compliance with the gamma dose-rate criteria also indicates compliance with the radon-222 flux target criteria. Therefore, in these cases a simple gamma screening measurement technique can be used to identify contaminated areas (>5 μr/hr) requiring cleanup. (As indicated above, if contamination profile indicates buried contamination, then this screening technique would not apply.)

Alternative or Upper Limit Criteria

The above target criteria have been developed as generic guidance to be used in developing decommissioning programs or plans. However, in some cases, site specific factors may need to be considered in determining the applicability of these land cleanup criteria. In particular, some balancing of the impacts of land cleanup vs. the costs and the benefits of returning the land for unrestricted use may need to be made on a site specific basis. Therefore, alternative criteria higher than the target criteria may be proposed based on site specific cost-benefit considerations. Although these alternate criteria may be higher than the target criteria, they must be below the following upper limit criteria:

1. The radon-222 flux (above background) at the soil-air interface shall not exceed a flux equivalent to 0.02 Working Levels (WL) inside a potential structure on the decommissioned site.
2. The gamma dose-rate in air one meter above the ground shall not exceed twenty (20) microroentgens per hour (above background).

OBJECTIVES AND RATIONALE

Objectives of Cleanup Criteria

The objectives of these cleanup criteria are to return the mill site to unrestricted use for any purpose whatsoever without any restrictions, control, or monitoring required.

Applicability of Cleanup Criteria

These criteria apply to the cleanup of a contaminated mill site and were developed based on a consideration of:

(a) The type of contamination expected,

(b) The depth of contamination,

(c) The radionuclides involved in the contamination, and

(d) The as low as reasonably achievable concept.

These criteria are meant to be applied to situations where soil concentrations at mill sites exceed these levels. In these cases the objective is to clean up (i.e., remove) the contamination. Therefore, these criteria would exclude the burial or dispersal of the contamination in order to meet the criteria.

Sources of Land Contamination

The primary source of land contamination at a uranium mill site are ore and tailings. Uranium ore contains uranium-238, uranium-234, thorium-230, radium-226, lead-210, and polonium-210 in equilibrium or close to equilibrium. Tailings are depleted in uranium (<10 percent of original content) but contain thorium-230, radium-226, lead-210, and polonium-210 which are in approximate equilibrium with each other. (NOTE: The loss of radon-222 from the ore and tailings would result in lead-210 and polonium-210 concentration of about 20 percent less than those of radium-226. Also, although only the long-lived members of the uranium-238 decay series are listed above, the dose assessments of these radionuclides take into consideration the short-lived members of the series.)

An analysis of the radiation exposure pathways from land contaminated with uranium ore and tailings indicates that radium-226 is the critical nuclide with respect to potential radiation exposure associated with future land use (see Appendices A-D). Therefore, the most restrictive criteria for contaminated land at a uranium mill site would be the radium-226 criteria. Since (as indicated above) the radium-226 is in equilibrium with other radionuclides which would be present, establishment of criteria which limits the amount of radium-226 contamination also assures that the other potential contamirants would be limited to an acceptable level.

Note

The proposed criteria do not apply to land contaminatied as a result of accidents involving yellowcake where uranium would be the primary source of contamination.

General Rationale for Criteria

In developing the proposed criteria, the following considerations were taken into account:

1. Radiation exposures to individuals using the land must be within current radiation exposure guidelines including the requirement that these exposures be as low as reasonably achievable.
2. These criteria must be consistent with criteria currently being applied or developed for similar type situations.
3. These criteria must take into account natural background concentrations of radionuclides in soil and must be distinguishable from these levels without requiring large costs associated with sampling and analysis.

4. These criteria must be enforceable; i.e., compliance with the criteria must be readily determinable, and the costs associated with determining compliance must not represent a substantial part of the cleanup costs.

Rationale for Target Criteria

The Target Criteria was chosen primarily on the basis that:

1. The radium-226 soil concentration, equivalent to the radon flux and gamma dose-rate criteria (for contamination distributed homogeneously in the subsurface soil), represents a concentration about equal to the upper range of natural background concentrations of radium-226 in soil in the mining and milling regions of the Western United States (see Appendix E). Therefore, because these levels are very close to background, they are believed to represent the lowest practical cleanup criteria.
2. A relatively simple gamma dose-rate survey can be used to identify area requiring cleanup and to demonstrate compliance with the criteria. This avoids complete dependence on costly and time-consuming soil sampling and analysis.

Rationale for Upper Limit Criteria

The Upper Limit Criteria were chosen primarily on the basis that:

1. These criteria would be consistent with the upper limits of Working Levels (WL) proposed by EPA for Florida phosphate lands and by DOE for the inactive uranium mill sites. (See Table II)
2. The resulting gamma dose-rates would not exceed the FRC guidance of 170 millirem/year for a suitable segment of the population.

TABLE I

SUMMARY OF POTENTIAL RADIATION DOSES TO INDIVIDUALS
FROM A DECOMMISSIONED MILL SITE

Exposure Pathway	Organ[a]	Target Criteria millirem/year	Upper Limit Criteria millirem/year
Inhalation of Radon Daughters	Bronchi	750[b]	2500
External	Whole-body	35	140
Inhalation of Particulates	Lung	5	17
Ingestion of Food	Bone	45	180

(a) Organ which would receive the highest dose from the exposure pathway.

(b) Based on projected Working Level inside structure of 0.006 WL.

TABLE II

COMPARISON OF EXPOSURES FROM PROPOSED CRITERIA WITH EXPOSURE CRITERIA FOR SIMILAR TYPE SITUATIONS

Exposure Pathway	Target Criteria	Upper Limit Criteria	Other Existing Criteria or Guidance
Inhalation of Radon Daughters	0.006 WL[a]	0.02 WL	0.033 WL - 10 CFR-20 0.01-0.05 WL - Surgeon General's Guidance 0.005-0.02 WL - EPA Florida Phosphate Guidance[b] 0.02 - DOE Criteria[b]
External (whole-body)	5 μr/hr (35 mrem/year)[c]	20 μr/hr (140 mrem/year)[c]	500 mrem/year - 10 CFR-20 170 mrem/year - FRC Guidance 400-900 mrem/year - Surgeon General's Guidance 25 mrem/year - 40 CFR-190
Inhalation of Particulates (Lung)	4 mrem/year	17 mrem/year	1500 mrem/year - 10 CFR-20 25 mrem/year - 40 CFR-190 10 mrem/year - EPA Transuranic Guidance[b]
Food Ingestion (Bone)	45 mrem/year	180 mrem/year	3000 mrem/year - 10 CFR-20 25 mrem/year - 40 CFR-190 30 mrem/year - EPA Transuranic Guidance[b]

(a) Average working level concentration inside structure predicted to be associated with radon flux target criteria (see Appendix A).

(b) Proposed criteria

(c) Based on shielding factor of 0.8

APPENDIX A

CALCULATION OF RADON-222 EXPOSURES INSIDE RESIDENCES ON DECOMMISSIONED MILL SITE

1. Radon Exhalation Rates from Soil

$$\phi = C \cdot d \cdot E \cdot \lambda \cdot l \cdot \frac{e^{x/l} - e^{-x/l}}{e^{x/l} + e^{-x/l}}$$

where:

ϕ = radon flux (pCi/cm^2-sec)

C = radium-226 pCi/gram soil

E = radon emanation rate = 0.2

λ = radon decay constant (sec^{-1}) - 2.1×10^{-6}

l = mean diffusion length in soil (cm)

x = depth of source (cm)

d = soil density (g/cc) = 1.6

ϕ = 0.33 - 1.0 pCi/m^2-sec when x = ∞, C = 1.0, and l = 50-150

ϕ = 0.02 pCi/m^2-sec when x = 2.5, C = 1.0, and l = 50-150

ϕ = 1.0 - 3.0 pCi/m^2-sec when x = ∞, C = 3.0, and l = 50-150

For l = 150, De = 1.7×10^{-2}, for l = 75, De = 8.5×10^{-3} and for l = 50, De = 1.9×10^{-3}, where De is the effective diffusion coefficient of radon-222 through soils when the void fraction (v) is 0.37.

Note: Radon exhalation rates from soils exhibit a wide variability and is a function of many factors. A mean diffusion range of 50-100 cm appears to bracket most of the flux measurements made for normal soils.

2. Radon Concentrations Inside Structures

The radon-222 concentrations inside structures from diffusion of radon from underlying soil may be estimated by the following calculation:

$$C = \frac{\phi A B}{V \lambda}$$

where:

C = radon-222 concentration (pCi/m^3)

ϕ = radon-222 flux (pCi/m^2-sec)

A = area over which flux enters structure (m^2)

B = flux reduction factor in entering structure

V = volume of structure (m^3)

λ = effective removal rate of radon-222 from the structure

3. Potential Exposures from Radon Inside Structures on Contaminated Land

Soil Conc. pCi/g ^{226}Ra	Rn-222 Flux pCi/m^2-sec	Working Levels (WL) Range[(a)]	Average[(b)]	Dose rem/year[(c)]
1.0	0.33-1.0	0.0002-0.008	0.002	0.25
3.0	1.0-3.0	0.0007-0.024	0.006	0.75
5.0	1.7-5.0	0.0024-0.04	0.012	1.25
10.0	3.3-10	0.0048-0.08	0.020	2.5

(a) Calculations based on B = 0.1 - 0.5, λ = 1-2 hrs, A/V = 0.41, and 1 pCi/l Rn-222 = .005 WL.

(b) Average value based on midpoint of the range of input parameters.

(c) Calculated on the basis of 25 WLM/year per WL (continuous exposure) and a dose conversion factor of 5 rem per working level month.

Note: The above calculations represent the range of working levels (WL) concentrations inside a structure from radon-222 entering the structure from the underlying soil. As can be seen from these calculations, many complex factors influence this concentration; and a very wide range is possible for any given radium-226 soil concentration. Diffusion of radon into a structure from underlying soil is only one potential source of radon inside structures. The working level concentrations inside a structure are also influenced by radon emanation from inside the structure (building materials) and also from outside ambient air.

APPENDIX B

CALCULATION OF EXTERNAL
WHOLE-BODY EXPOSURES FROM DECOMMISSIONED MILL SITE

1. Dose Conversion Factors for Whole-Body from Contaminated Ground

Radionuclide	Millirem/year pCi/gram[(a)]
$^{238}U \rightarrow ^{234}U$	<1
^{230}Th	<1
$^{226}Ra \rightarrow ^{206}Pb$	16

(a) At a depth of about one foot or greater.

2. Potential Doses from External Exposures

Radionuclides	Millirem/year* 1 pCi/g	3 pCi/g	10 pCi/g
$^{230}U \rightarrow ^{234}U$	<1	<1	<1
^{230}Th	<1	<1	<1
$^{226}Ra \rightarrow ^{206}Pb$	13	39	130
TOTAL	13	39	130

*Includes shielding factor of 0.8.

APPENDIX C

CALCULATION OF INHALATION EXPOSURE FROM RESUSPENDED PARTICULATES FROM DECOMMISSIONED MILL SITE

1. Dose Conversion Factors for Lung

Radionuclide	Millirem-m³ / year - pCi
^{226}Ra	7.3×10^3
^{230}Th	3.2×10^3
^{234}U	3.3×10^3
^{238}U	2.8×10^3
^{210}Pb	2.7×10^3
^{210}Po	8.0×10^2

These dose conversion factors were calculated using the Task Group Lung Model for a "y" compound with an AMAD-1.0 µ.

2. Soil Concentrations Resulting in Inhalation Doses of 1 Millirem/Year

$$\text{Soil Concentration (pCi/g)} = \frac{\text{Air Concentration (pCi/m}^3\text{)}}{\text{Resuspension Factor (m}^{-1}\text{)} \times 1.5 \times 10^4 \text{ g/m}^2}$$

Radionuclide	Soil Concentration pCi/g
^{226}Ra	9.2
^{230}Th	20
^{234}U	20
^{238}U	23
^{210}Pb	25
^{210}Po	83

Resuspension Factor = 10^{-9} m^{-1}

3. Potential Doses from Inhalation of Resuspended Particulates

Radionuclide	Millirem/year[a]		
	1 pCi/g	15 pCi/g[b]	60 pCi/g[c]
^{226}Ra	0.1	1.5	6.0
^{230}Th	0.05	0.75	3.0
^{234}U	0.05	0.75	3.0
^{238}U	0.04	0.60	2.4
^{210}Pb	0.04	0.60	2.4
^{210}Po	0.01	0.15	0.6
TOTAL	0.29	4.35	17.4

(a) 50-year dose commitment from one year's intake.

(b) Maximum concentrations of radionuclides in upper 2.5 cm of soil which would be equivalent to a gamma dose rate of 5 μr/hr.

(c) Maximum concentrations of radionuclides in upper 2.5 cm of soil which would be equivalent to a gamma dose rate of 20 μr/hr.

APPENDIX D

CALCULATION OF INGESTION
EXPOSURES FROM DECOMMISSIONED MILL SITE

1. Dose Conversion Factors for Bone[(a)]

Radionuclide	Millirem/pCi Intake
^{226}Ra	0.03
^{230}Th	0.002
^{234}U	0.0008
^{238}U	0.0007
^{210}Pb	0.044
^{210}Po	0.001

(a) Bone is the organ which receives the highest dose from ingestion of these radionuclides (taken collectively).

2. Ingestion Doses to Bone Per pCi/g of Soil

	millirem/year(a,b,c)	
Radionuclide	Resuspended Particulates	Root Uptake
^{234} + ^{238}U	<0.01	0.4
^{230}Th	<0.01	0.8
^{226}Ra	0.25	1.5
^{210}Pb	0.10	11
^{210}Po	<0.01	0.9
TOTAL	0.35	14.6

(a) These doses were calculated using equation C-7 in Regulatory Guide 1.109 (March 1976). The transfer data used were the values in Table C-5 of Regulatory Guide 1.109 except as noted below. Calculations were made using a resuspension factor of 10^{-9} m^{-1} and a deposition velocity (V_d) of 0.01 m/sec.

(b) These doses were calculated on the assumption that an individual raised 50 percent of his food on the decommissioned mill site. The staff believes this to be a conservative assumption since it is highly unlikely that an individual would raise this amount of his own food at a decommissioned mill site.

(c) The vegetation-soil transfer parameters in Regulatory Guide 1.109 overestimate the concentration of these nuclides in food (by a factor of 10-100). Therefore, for this assessment, a soil-food relationship derived from NCRP-45 was used in calculating doses from root uptake for these radionuclides. These relationships were 1 pCi/g of soil = 1.4 pCi/d of ^{210}Pb intake and 1 pCi/g of soil = 1.8 pCi/d of ^{210}Po intake. (These values would be reduced by a factor of two if only 50 percent of a person's food was raised on the contaminated land).

3. Potential Doses to Individuals at a Decommissioned Mill Site from Locally Raised Food

Pathway	millirem/year(c) (Bone)
Foiliar Deposition(a)	
15 pCi/g ^{226}Ra	5
60 pCi/g ^{226}Ra	20
Root Uptake(b)	
3 pCi/g ^{226}Ra	45
12 pCi/g ^{226}Ra	180

(a) Based on maximum concentrations of radionuclides in upper 2.5 cm of soil which would be equivalent to gamma dose-rates of 5 μr/hr and 20 μr/hr.

(b) Based on the maximum concentrations in subsurface soil (including root zone) which would be equivalent to gamma dose-rates of 5 and 20 μr/hr.

(c) Doses are based on assumption of equilibrium of all members of the uranium decay series.

Note: The ingestion pathway model (food chain to man) and the terrestrial transfer parameters used in that model (for the radionuclides in the uranium-238 decay series) are not well established and still need to be verified and confirmed. However, it is the staff's judgment that the calculated doses presented above are conservative estimates of the potential doses an individual could receive from raising food on a decommissioned mill site meeting the proposed cleanup criteria. Nevertheless, because of the uncertainty existing in these models, there is an urgent need to evaluate the applicability of present terrestrial food pathway models for members of the uranium-238 decay series and to determine the appropriateness of the transfer parameters used in these models. This evaluation is necessary to confirm our assessments using the models and to provide the necessary confidence in conclusions based on these models.

APPENDIX E

RADIUM-226 SOIL CONCENTRATIONS
OF WESTERN UNITED STATES MILLING REGIONS

Location	Radium-226, pCi/g Mean	Radium-226, pCi/g Range
Shiprock, N.M.	1.7	1.3 - 2.6
Salt Lake City, Utah	1.5	1.0 - 2.1
Mexican Hat, Arizona	0.8	0.5 - 1.7
Tuba City, Arizona	0.95	0.5 - 3.4
Ray's Point, Texas	0.9	0.5 - 1.4
Falls City, Texas	0.9	0.5 - 1.4
Lakeview, Oregon	0.7	0.2 - 2.1
Lowman, Idaho	1.2	0.6 - 1.6
Riverton, Wyoming	1.1	0.7 - 1.7
Converse County, Wyoming	1.0	0.7 - 1.7
Rifle, Colorado	1.5	0.5 - 3.4
Ambrosia Lake, N.M.	1.0	0.7 - 1.2

Data from DOE Phase II Reports on Assessment of Inactive Uranium Mill Tailings.

POOR ORIGINAL

FIGURE 2

RADIUM-226 CONCENTRATIONS IN SOIL AT VARIOUS DEPTHS
WHICH WILL PRODUCE A RADON-222 FLUX EQUIVALENT TO
3 pCi/g OF RADIUM-226 AT INFINITE THICKNESS

(Calculations based on mean diffusive length of 150 cm.)

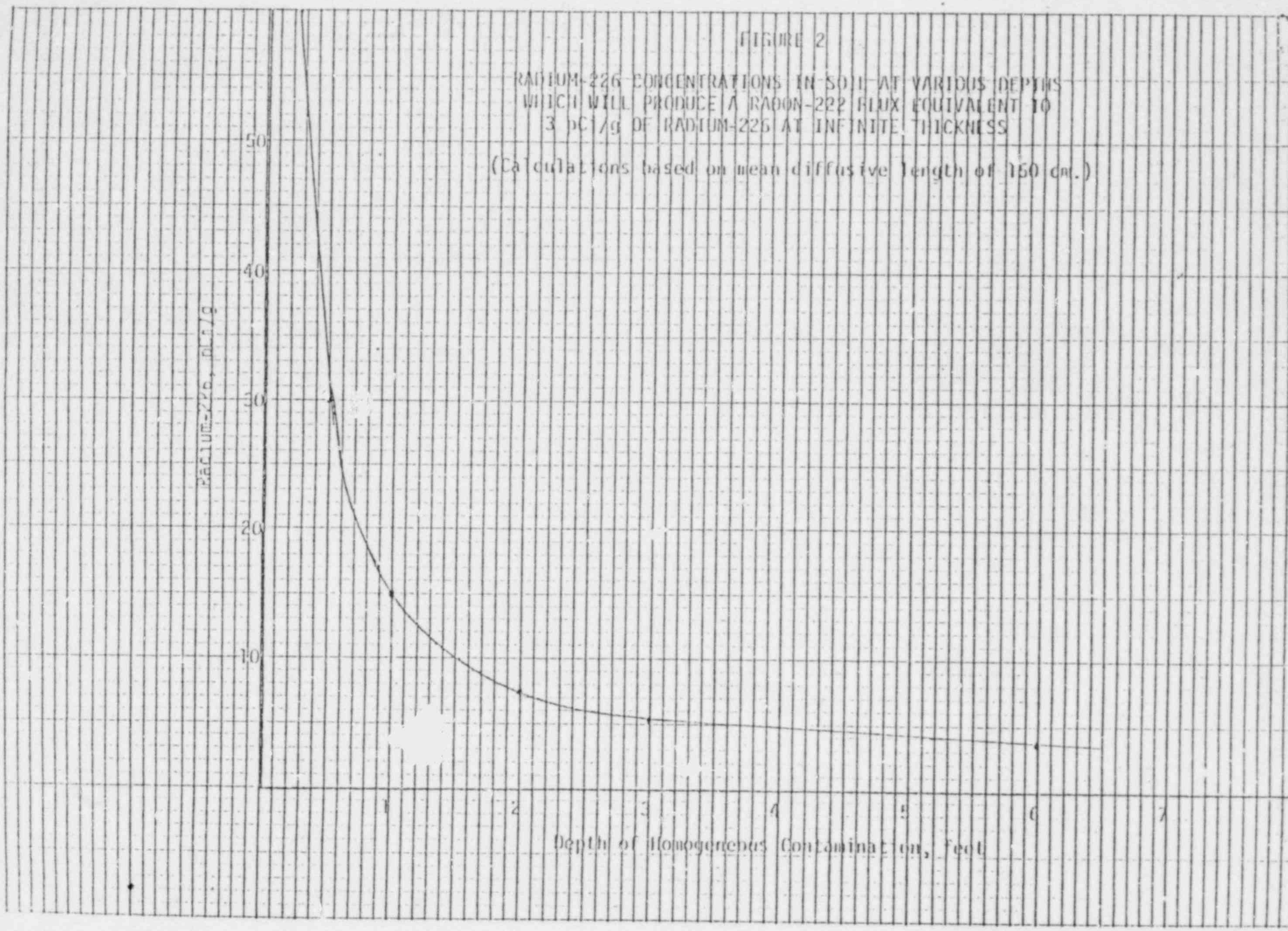

FIGURE 1

RADIUM-226 CONCENTRATIONS IN SOIL AT VARIOUS DEPTHS WHICH WILL PRODUCE A GAMMA DOSE RATE OF 5 μr/hr

(These are approximate values for illustrative purposes only. Calculations based on the relationship that 1 pCi/g of radium-226 in soil at infinite thickness will result in a gamma dose-rate of 1.8 μr/hr.)