Derivation of Residual Radioactive Material Guidelines for the Laboratory for Energy- Related Health Research Site

T. E. Chapman

November 1993

**Prepared for the U.S. Department of Energy
San Francisco Operations Office
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
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operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

DERIVATION OF RESIDUAL RADIOACTIVE
MATERIAL GUIDELINES FOR THE
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SUMMARY

Residual radioactive material guidelines were derived for the Laboratory for Energy-Related Health Research (LEHR) Environmental Restoration (ER) site in Davis, California. The guideline derivation was based on a dose limit of 100 mrem/yr. The U.S. Department of Energy (DOE) residual radioactive material guideline computer code was used in this evaluation. This code implements the methodology described in the DOE manual for implementing residual radioactive material guidelines. Three potential site utilization scenarios were considered with the assumption that following ER action, the site will be used without radiological restrictions. The defined scenarios vary with regard to use of the site, time spent at the site, and sources of food consumed. The results of the evaluation indicate that the basic dose limit of 100 mrem/yr will not be exceeded, provided that the soil concentrations of these radionuclides at the LEHR site do not exceed the scenario-specific values calculated by this study. Except for the extent of the contaminated zone (which is very conservative), assumptions used are as site-specific as possible, given available information. The derived guidelines are single-radionuclide guidelines and are linearly proportional to the dose limit used in the calculations. In setting the actual residual soil contamination guides for the LEHR site, DOE will apply the as low as reasonably achievable policy to the decision-making process, along with other factors such as whether a particular scenario is reasonable and appropriate, as well as using site-specific inputs to computer models based on data not yet fully determined.

ACRONYMS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as Amended
DOE	U.S. Department of Energy
ER	Environmental Restoration
ERDA	U.S. Energy Research and Development Administration
LEHR	Laboratory for Energy-Related Health Research
NPL	National Priorities List
PNL	Pacific Northwest Laboratory
RESRAD	residual <i>radioactive</i> material guideline computer code
SARA	Superfund Amendments and Reauthorization Act of 1986
UC Davis	University of California, Davis

UNITS OF MEASURE

°C	degrees Celsius
°F	degrees fahrenheit
cm	centimeter(s)
cm ³	cubic centimeter(s)
d	day(s)
ft	foot (feet)
ft ²	square foot (feet)
g	gram(s)
h	hour(s)
ha	hectare(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
m	meter(s)
m ²	square meter(s)
mi	mile(s)
mrem	millirem(s)
pCi	picocurie(s)
rem	roentgen equivalent man
s	second(s)
w	week(s)
yd ²	square yard(s)
yr	year(s)

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1.0 INTRODUCTION AND BRIEF HISTORY

The Laboratory for Energy-Related Health Research (LEHR) was operated by the University of California, Davis (UC Davis) for the U.S. Department of Energy (DOE). The land is owned by the Regents of the University of California and leased to the DOE; the structures at LEHR are owned by DOE (DOE 1988). A variety of operations involving the use of radioactive materials were conducted at the site between 1958 and 1989. Potential contaminated areas exist at the site from past disposal practices associated with UC Davis campus activities and with DOE-sponsored research activities at LEHR. The DOE began environmental restoration (ER) of the LEHR site in 1989 to verify that conditions, i.e., residual hazardous and radioactive materials, meet current federal guidelines. The DOE, San Francisco Operations Office has contracted with Pacific Northwest Laboratory^(a) to manage the ER of the LEHR site.

The LEHR facility is currently proposed to be on the National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. A preliminary assessment of the LEHR facility was completed in 1988, and the hazard ranking system process is being completed by the U.S. Environmental Protection Agency (Dames & Moore 1993). Depending on the ranking, the ER of LEHR could be required to comply with CERCLA. DOE, at its own initiative, has undertaken a CERCLA-based remedial investigation. However, at this time, the site is not under any regulatory enforcement action.

The proposed remedial action for the site will follow the guidelines established in DOE Order 5400.5 (DOE 1990). The residual radioactive material guideline computer code (RESRAO) is used to derive residual radioactive material guidelines on a site-specific basis (Gilbert et al. 1989). This report presents the conservative guidelines derived to guide the ER process for the LEHR site. The derivation of these guidelines was based on the requirement that the 50-yr committed effective dose equivalent to a

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hypothetical individual who lives or works in the immediate vicinity of the LEHR site should not exceed a dose of 100 mrem/yr following remedial action. The guidelines calculated by this study are intended to provide "worst case," i.e., conservative, values to guide the ER process. The determination of residual soil contamination criteria for the ER project should be based on site-specific geological, hydrological, and contamination data not yet fully quantified.

1.1 SITE DESCRIPTION AND SETTING

The LEHR site is located approximately 2.4 km (1.5 mi) south of the main UC Davis campus and the city of Davis, and approximately 1.2 km (0.75 mi) south of Interstate 80 on County Road 79 (Figure 1). The LEHR site covers approximately 6.1 ha (15 acres) and contains several buildings, including a main administration and office building, two animal hospitals, laboratory and support buildings, waste-handling facilities, and numerous outside dog pens (Figure 2).

Also located on the LEHR site are two cells of an inactive UC Davis landfill, a UC Davis low-level radioactive waste disposal site, and a DOE low-level radioactive waste disposal site.

The LEHR site is located in a rural area and is bounded on all sides by UC Davis property. The southern border of the LEHR facility is the northern levee on the South Fork of Putah Creek. Private land surrounds the UC Davis property on all sides. Land use in the vicinity of UC Davis and the LEHR facility is predominantly agricultural. Approximately 60% of Solano County's total area is farmland and 18% is irrigated cropland (U.S. Bureau of Census 1989). The current population of Davis is approximately 46,000, and the current population of Solano County is about 340,400 (U.S. Bureau of the Census 1991).

Surface soil at the LEHR facility is classified in the Reiff series as a fine sandy loam. The dominant texture of the upper subsoil is sandy, and the dominant texture of the lower subsoil is gravelly, loamy (silty) sand. The soil is characterized by a deep, permeable profile and good drainage (Dames & Moore 1993).

FIGURE 1. Location of the LEHR Site

FIGURE 2. Map of the LEHR Site

Groundwater beneath the site ranges in depth from approximately 13.7 to 21.3 m (45 to 70 ft) below ground surface and has been divided into two zones (Dames & Moore 1993). The first hydrostratigraphic unit consists of fine-grained sediment varying from very fine-grained sandy silt to sandy clay. The second hydrostratigraphic unit consists of coarse sand and cobble gravel. Because of the agricultural use of nearby land, many domestic and supply wells are located close to the LEHR facility; however, no active groundwater wells are present on the LEHR site. The climate in the region of the LEHR facility is temperate with mild winters and long summers. The average temperature is 8.3°C (46.9°F) in winter and 23°C (73°F) in summer (National Oceanic and Atmospheric Administration 1985; DOE 1988). The mean annual precipitation at the Davis Meteorological Station is 43 cm (17.0 in.), most of which occurs between October and April (National Climatic Data Centers 1992). From the winter of 1986-1987 until the winter of 1992-1993, most of California, including the Davis area, experienced drought conditions. Regionally, the drought resulted in decreased aquifer recharge thus groundwater levels have decreased due to the effects of drought and pumping for agricultural, municipal, and industrial uses.

1.2 SITE HISTORY

Full-scale experimental use of radioactive materials began at LEHR in 1960. In the initial stages of operation at the LEHR facility, waste was handled through a central waste-handling facility on the main campus. However, because of safety concerns, waste handling for LEHR-generated waste was returned to the LEHR facility in the early 1960s.

Portions of the LEHR site were previously used as the UC Davis campus landfill, which consisted of three separate disposal units (two of which are located on the LEHR site). Disposal in the oldest unit (Inactive Disposal Unit No. 1) began in the 1940s and ceased in either the late 1950s or early 1960s. The area is now covered by the Cobalt-60 Irradiator Field at the LEHR facility (Figure 2). The next oldest disposal area (Inactive Disposal Unit No. 2) received wastes from 1956 to 1967. This disposal area is partially covered with the eastern-most sections of two sets of dog pens used to house the beagles (used for animal research) at the LEHR facility. A third landfill

disposal unit, located about 180 m (600 ft) east of LEHR (Inactive Disposal Unit No. 3), was used from 1963 to 1967.

Laboratory research continued through sponsorship of the U.S. Energy Research and Development Administration (ERDA) (predecessor to DDE) and DOE until funding for the DOE-related work was terminated in fiscal year 1989 (except for limited data evaluation). During the 30-year operation of the LEHR facility, various wastes were generated and disposed of on-site. These wastes included radioactive, biological, chemical, municipal, and laboratory debris.

In 1987, a DDE team conducted an environmental survey of the facility to identify environmental problems and risks associated with LEHR. This survey concluded that several potential environmental threats existed at the LEHR facility. Waste burial sites, the Imhoff treatment tanks, septic system, and associated leach fields (Strontium-90 Leach Fields) were considered to be potential sources of chemical and radioactive leachate to groundwater. Additionally, dog pen and cobalt-60 irradiation activities were considered to be potential sources of soil contamination (DOE 1988).

During 1987 and 1988, Wahler Associates conducted groundwater and soils investigations at LEHR (the Phase I study) to evaluate chemical radioactive contamination in the soils and groundwater at the site. The purpose of this study was to provide a basis for subsequent investigations and monitoring at the site (Wahler Associates 1988, 1989).

In early 1990, Dames & Moore began the Phase II Site Characterization study. The results of this survey indicated the presence of residual radioactive contamination, primarily radium-226 and strontium-90, in on-site soil (Dames & Moore 1993). A maximum concentration of 19 pCi/g of strontium-90 was detected in one sample from the northern part of LEHR; maximum concentrations of 0.61, 0.70, 0.22, and 0.10 pCi/g of strontium-90 were detected in the radium-226 seepage pits, southwest chemical dispensing area, dog pen areas, and north chemical dispensing area, respectively. No strontium-90 was reported in samples analyzed from the strontium-90 leach field. Average background soil concentrations of strontium-90 ranged from nondetectable (<0.05 pCi/g) to 0.24 pCi/g. Cesium-137 was detected in the

radium-226 seepage pits, dog pen area, and strontium-90 leach field area. The cesium-137 concentrations in these three areas were at or below the maximum measured background concentration of 0.2 pCi/g.

Average background soil concentrations of radium-226 ranged from 0.05 pCi/g to 1.4 pCi/g. Maximum reported activities (including contributions from background) of radium-226 of 1.31 pCi/g in North Chemical Dispensing area, 0.75 pCi/g in the Strontium-90 Leach Fields, 1.35 pCi/g in the Radium-226 Dry Well Area, 0.9 pCi/g in the Southwest Chemical Dispensing Area, 1.4 pCi/g in the Dog Pen Area. Radium-226 daughter products were also detected in soil samples from several areas of the LEHR site.

1.3 DERIVATION OF CLEANUP GUIDELINES

Most DOE cleanup guidelines applicable to remedial actions are generic in nature, including the guideline for radium-226 in soil; however, guidelines for strontium-90 and cesium-137 in soil are derived on a site-specific basis (DOE 1990, 1992). The purpose of this report is to present the residual radioactive material guidelines applicable to guide remedial action at the LEHR site, i.e., the residual concentrations of long-lived radioactive materials in a homogeneously contaminated area that must not be exceeded if the site is to be released for use without radiological restrictions. The derivation of site-specific, single-radionuclide guidelines for the LEHR site is based on a dose limit of 100 mrem/yr to a member of the public (DOE 1990, 1992) and the assumption that a single radionuclide is the only radionuclide present at an above-background concentration. The RESRAD computer code, which implements the methodology described in the DOE manual for implementing residual radioactive material guidelines (Gilbert et al. 1989), was used to derive these guidelines. The guidelines are intended to guide remediation only, and actual site-specific, residual radioactive material soil guidelines should be determined by DOE using more appropriate site-specific data, when available, taking into account other sociological, economical, and political factors.

2.0 LAND-USE SCENARIOS

Three potential plausible exposure scenarios are considered for the LEHR site. All scenarios assume that, at some time following remediation, the site will be released for use without radiological restrictions.

Scenario 1 assumes research use of the site (ANL 1993). Under this scenario, a hypothetical individual is assumed to work in the area of the site for 8 h/d (6 h outdoors and 2 h indoors), 5 d/w, 50 w/yr. Therefore, in 1 yr, the research worker is assumed to spend 17% of the time working outdoors at the site, 6% of the time working indoors at the site, and 77% of the time away from the site. It is assumed that the worker does not ingest water, plant foods, or fish obtained from the remediated area, or meat or milk from livestock raised in the remediated area.

Scenario 2 assumes recreational use of the site. Under this scenario, it is assumed that, at some time in the future, the whole site is transformed into a public recreational park and a hypothetical individual spends 15 h/w, 50 w/yr, in the remediated area of the park. Therefore, in 1 yr, this generic recreationist is assumed to spend 9% of the time in the remediated area and 91% of the time away from the site. It is assumed that the recreationist does ingest water obtained from the remediated area, but does not ingest plant foods, meat, or milk from livestock raised in the remediated area. Also, it is assumed that a portion of any fish or other aquatic food consumed by the recreationist is obtained from the site. This scenario assumes that drinking water supplies for the park area, if any, are from an onsite source, i.e., a well. Additionally, this scenario assumes that fishing is allowed in the Putah Creek nature area.

Scenario 3 assumes agricultural use of the site (ANL 1993). Under this scenario, it is assumed that at some time in the future, the whole site is transformed into a farm and, in 1 yr, a hypothetical resident farmer spends 50% of the time indoors in the remediated area, 25% of the time outdoors in the remediated area, and 25% of the time away from the site. The resident farmer is assumed to ingest plant foods grown in the garden and fish and other aquatic food obtained from the site. This individual is also assumed to

ingest meat and milk obtained from livestock raised in the remediated area. The resident's drinking water supply is assumed to be from an on-site well.

Potential radiation doses resulting from eight exposure pathways are analyzed as follows:

- direct exposure to external gamma radiation from the decontaminated soil material
- internal radiation from inhalation of contaminated dust including radon and its progeny when applicable
- internal radiation from ingestion of plant foods grown in the remediated area and irrigated with water from local groundwater wells
- internal radiation from ingestion of meat obtained from livestock fed with fodder grown in the remediated area and with water drawn from inside the area
- internal radiation from ingestion of milk obtained from livestock fed with fodder grown in the remediated area and with water drawn from inside the area
- internal radiation from ingestion of water drawn from inside the area
- internal radiation from ingestion of fish and other aquatic food obtained from the site
- internal radiation from ingestion of on-site soil.

All pathways considered for scenarios 1, 2, and 3 are summarized in Table 1.

TABLE 1. Summary of Pathways for Scenarios 1, 2, and 3 at the LEHR Site

<u>Pathway</u>	<u>Scenario 1 (Researcher)</u>	<u>Scenario 2 (Recreationist)</u>	<u>Scenario 3 (Resident Farmer)</u>
External Gamma Exposure	Yes	Yes	Yes
Inhalation of dust	Yes	Yes	Yes
Ingestion of Plant Foods	No	No	Yes
Ingestion of Meat	No	No	Yes
Ingestion of Milk	No	No	Yes
Ingestion of Fish	No	Yes	Yes
Ingestion of Soil	Yes	Yes	Yes
Ingestion of Water	No	Yes	Yes

Using the RESRAD computer code (Gilbert et al. 1989) to calculate potential radiation doses to the hypothetical future researcher, recreationist, or resident farmer, the following assumptions were made for these scenarios:

- During 1 yr, the researcher spends 1500 h (17%) outdoors at the site, 500 h (6%) indoors at the site, and 6760 h (77%) away from the remediated area; the recreationist spends 750 h/yr (9%) on-site; and the resident farmer spends 4380 h (50%) indoors, 2190 h (25%) outdoors in the remediated area, and 2190 h (25%) away from the site.
- The walls, floors, and foundation of the house or office building reduce external exposure by 30%.
- The indoor dust level in the house or office building is 40% of the outdoor dust level (Gilbert et al. 1989).
- 50% of the plant food diet consumed by the resident farmer is grown in a garden in the remediated area. Neither the researcher nor the recreationist consumes these plant foods.
- The size of the remediated area is sufficient to grow all of the forage needed for raising livestock in the remediated area to produce sufficient meat and milk for the resident farmer. Neither the researcher nor the recreationist consumes this meat or milk.
- 50% of the fish and other aquatic food consumed by the farmer is obtained from the site and 5% for the recreationist. The researcher does not consume aquatic food obtained from the site.
- After remedial action, no cover material is placed over the remediated area.
- The thickness of the contaminated zone is a very conservative average value derived from Dames & Moore (1993) measurements. The whole area of the LEHR site (60,700 m² [653,400 ft²]) is conservatively assumed to be homogeneously contaminated to a thickness of 9.1 m (30 ft).

The input parameters for the RESRAD computer program are listed in the Appendix.

3.0 RESIDUAL RADIOACTIVE MATERIAL GUIDELINES

The residual radioactive material guideline is the concentration of residual radioactive material that can remain in a remediated area and still allow use of the area without radiological restrictions. On the basis of the DOE annual radiation dose limit of 100 mrem/yr for an individual member of the public (DOE 1990, 1992), the single-radionuclide residual, radioactive material guideline, G_i , for the LEHR site can be calculated as

$$G_i = 100/DSR_i, \quad (1)$$

where DSR_i is the total dose/source concentration ratio. The calculated residual radioactive material guidelines for radionuclides at the LEHR site are presented in Tables 2, 3, and 4. The derived guidelines are linearly proportional to the dose limit used in the calculation. The radionuclides listed in Tables 2, 3, and 4 are those that the RESRAD computer code is capable of calculating. Therefore, the presence of a radionuclide in Table 2, 3, or 4 does not indicate that it is potentially present on the LEHR site.

When implementing the derived radionuclide guidelines for decontamination of a site, the sum-of-fractions rule applies. That is, the

TABLE 2. Soil Residual Radioactive Material Guidelines, Scenario 1

<u>Radioisotope</u>	<u>Residual Radioactive Material Guideline (pCi/g)</u>
Ac-227	3.5E+01
Am-241	4.7E+02
Am-243	2.2E+02
C-14	6.4E+06
Ca-41	1.0E+07
Ce-144	1.4E+03
Cl-36	3.9E+05
Cm-243	3.4E+02
Cm-244	9.7E+02
Co-60	2.0E+01
Co-57	9.0E+02
Cs-134	4.2E+01
Cs-135	1.9E+06
Cs-137	9.1E+01 ^(a)

TABLE 2. (contd)

<u>Radioisotope</u>	<u>Residual Radioactive Material Guideline (pCi/g)</u>
Eu-152	4.6E+01
Eu-154	4.1E+01
Eu-155	2.7E+03
Fe-55	1.6E+07
Gd-152	1.2E+03
H-3	2.1E+08
I-129	1.1E+04
K-40	3.8E+02
Mn-54	7.7E+01
Na-22	2.9E+01
Nb-94	3.2E+01
Ni-63	1.7E+07
Ni-59	2.8E+07
Np-237	1.8E+02
Pa-231	3.0E+01
Pb-210	1.8E+03
Pu-240	5.1E+02
Pu-241	1.5E+04
Pu-242	5.4E+02
Pu-238	5.7E+02
Pu-239	5.1E+02
Ra-226	2.6E+01
Ra-228	3.4E+01
Ru-106	3.3E+02
Sb-125	1.6E+02
Sm-151	8.4E+06
Sr-90	7.1E+04 ^(a)
Tc-99	8.3E+06
Th-230	3.3E+01
Th-232	1.8E+01
Th-228	3.2E+01
Th-229	8.6E+01
U-232	3.3E+01
U-233	7.2E+01
U-234	8.3E+01
U-235	3.5E+02
U-236	2.4E+03
U-238	1.4E+03

^(a)Taken from Table 4, ANL 1993.

TABLE 3. Soil Residual Radioactive Material Guidelines, Scenario 2

<u>Radioisotope</u>	<u>Residual Radioactive Material Guideline (pCi/g)</u>
Ac-227	8.0E+01
Am-241	1.0E+03
Am-243	1.5E+01
C-14	9.1E+01
Ca-41	3.7E+06
Ce-144	3.5E+03
Cl-36	3.5E+03
Cm-243	3.2E+00
Cm-244	5.4E+00
Co-57	2.2E+03
Co-60	4.9E+01
Cs-134	1.0E+02
Cs-135	4.3E+06
Cs-137	2.2E+02
Eu-152	1.1E+02
Eu-154	1.0E+02
Eu-155	6.7E+03
Fe-55	3.8E+07
Gd-152	3.8E+01
H-3	6.5E+06
I-129	2.7E+02
K-40	1.6E+02
Mn-54	1.8E+02
Na-22	7.2E+01
Nb-94	7.3E+00
Ni-59	6.6E+07
Ni-63	3.8E+07
Np-237	3.5E+00
Pa-231	4.3E+01
Pb-210	4.0E+03
Pu-238	1.2E+03
Pu-239	1.1E+03
Pu-240	1.1E+03
Pu-241	3.6E+04
Pu-242	1.1E+03
Ra-226	7.1E+01
Ra-228	8.4E+01
Ru-106	8.2E+02
Sb-125	3.9E+02
Sm-151	2.0E+04
Sr-90	1.6E+05
Tc-99	3.8E+04
Th-228	7.9E+01
Th-229	2.0E+02
Th-230	9.0E+01
Th-232	4.4E+01

TABLE 3. (contd)

<u>Radioisotope</u>	<u>Residual Radioactive Material Guideline (pCi/g)</u>
U-232	8.1E+01
U-233	1.6E+03
U-234	2.0E+03
U-235	2.1E+02
U-236	5.5E+03
U-238	3.4E+03

TABLE 4. Soil Residual Radioactive Material Guidelines, Scenario 3

<u>Radioisotope</u>	<u>Residual Radioactive Material Guideline (pCi/g)</u>
Ac-227	9.0E+00
Am-241	1.6E+02
Am-243	1.1E+01
C-14	9.0E+00
Ca-41	1.4E+04
Ce-144	5.0E+01
Cl-36	8.9E+00
Cm-243	2.3E-01
Cm-244	3.8E-01
Co-60	7.0E+00
Co-57	3.1E+01
Cs-134	1.4E+01
Cs-135	2.8E+03
Cs-137	3.2E+01 ^(a)
Eu-152	1.6E+01
Eu-154	1.4E+01
Eu-155	9.6E+02
Fe-55	1.7E+06
Gd-152	2.7E+00
H-3	6.8E+04
I-129	3.8E+00
K-40	1.5E+01
Mn-54	2.7E+01
Na-22	1.0E+01
Nb-94	7.4E-01
Ni-63	8.9E+04
Ni-59	2.3E+05
Np-237	1.8E-01
Pa-231	3.0E+00

TABLE 4. (contd)

<u>Radioisotope</u>	<u>Residual Radioactive Material Guideline (pCi/g)</u>
Pb-210	2.4E+00
Pu-240	1.7E+02
Pu-241	5.3E+03
Pu-242	1.8E+02
Pu-238	1.9E+02
Pu-239	1.7E+02
Ra-226	1.9E+00
Ra-228	1.1E+01
Ru-106	1.1E+02
Sb-125	5.6E+01
Sm-151	1.4E+03
Sr-90	3.7E+01 ^(a)
Tc-99	5.5E+02
Th-230	2.4E+00
Th-232	5.9E+00
Th-228	1.0E+01
Th-229	2.0E+01
U-232	1.1E+01
U-233	1.7E+02
U-234	6.1E+01
U-235	1.5E+01
U-236	6.1E+01
U-238	4.1E+02

^(a)Taken from Table 4, ANL 1993.

summation of the fractions of radionuclide concentrations, S_i , remaining onsite, averaged over an area of 100 m² (120 yd²) and a depth of 15 cm (6 in.) and divided by their guidelines, G_i , should not be greater than unity, or

$$\sum_i S_i/G_i \leq 1. \quad (2)$$

The derived residual radioactive material guidelines for the LEHR site are single-radionuclide guidelines for a large, homogeneously contaminated area. For smaller isolated areas of contamination, the allowable concentration that can remain on-site may be higher than the homogeneous guideline, depending on the size of the area of contamination.

In setting the actual radionuclide guidelines for the LEHR site, DOE will apply the as low as reasonably achievable (ALARA) policy to the decision-making process, along with other factors, such as whether a particular scenario is reasonable and appropriate. Additionally, soil guides should be revised to account for actual site-specific hydrology, geology, and other physical factors determined during the site remedial investigation. The guidelines presented in this study should be applied only by health physicists or other persons experienced in performing health physics computer modeling for the environment.

4.0 REFERENCES

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APPENDIX

PARAMETERS USED IN THE ANALYSIS OF THE LEHR SITE

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The parametric values used in the RESRAD code for the analysis of the LEHR site are listed in Table A.1. All parametric values are reported at up to three significant figures. Some values are specific to the LEHR site, others are generic. The assumptions for each of these scenarios are as follows:

- Scenario 1 - Continued research use of the site. A hypothetical person is assumed to work in the area of the site.
- Scenario 2 - Recreational use of the site. A hypothetical recreationist is assumed to spend some time during the year at a public park constructed on the remediated area.
- Scenario 3 - Residential use of the site. A hypothetical resident farmer is assumed to live in the remediated area.

TABLE A-1. Parameters Used in the RESRAD Code for Analysis of the LEHR Site

<u>Parameter</u>	<u>Unit</u>	<u>Value</u>		
		<u>Scenario 1</u>	<u>Scenario 2</u>	<u>Scenario 3</u>
Area of contaminated zone ^a	m ²	60,700	60,700	60,700
Thickness of contaminated zone ^a	m	9.1	9.1	9.1
Length parallel to aquifer flow ^a	m	Not used	246	246
Cover depth ^a	m	0	0	0
Density of contaminated zone ^a	g/cm ³	1.35	1.35	1.35
Contaminated zone erosion rate ^b	m/yr	0.001	0.001	0.001
Contaminated zone total porosity ^a	-	0.4	0.4	0.4
Contaminated zone effective porosity ^a	-	0.2	0.2	0.2
Contaminated zone hydraulic conductivity ^a	m/yr	200	200	200
Contaminated zone b parameter ^a	-	7.12	7.12	7.12
Evapotranspiration coefficient ^b	-	0.6	0.6	0.6
Precipitation ^a	m/yr	0.43	0.43	0.43
Irrigation ^b	m/yr	0.2	0.2	0.2
Irrigation mode ^b	-	Overhead	Overhead	Overhead
Runoff coefficient ^b	-	0.4	0.4	0.4
Watershed area for nearby pond ^a	m ²	Not used	1,000,000	1,000,000
Density of saturated zone ^a	g/cm	Not used	1.7	1.7

TABLE A-1. (contd)

Parameter	Unit	Value		
		Scenario 1	Scenario 2	Scenario 3
Saturated zone total porosity ^b	-	Not used	0.4	0.4
Saturated zone effective porosity ^a	-	Not used	0.2	0.2
Saturated zone hydraulic conductivity ^a	m/yr	Not used	3,076	3,076
Saturated zone hydraulic gradient ^a	-	Not used	0.03	0.03
Saturated zone b parameter ^a	-	Not used	7.75	7.75
Water table drop rate ^b	m/yr	Not used	0.001	0.001
Well pump intake depth (below water table) ^b	m	Not used	10.0	10.0
Model: nondispersion (ND) or mass-bal. (MB) ^b	-	Not used	ND model	ND model
Number of unsaturated zone strata ^a	-	Not used	1	1
Unsaturated zone 1, thickness ^a	-	Not used	13.7	13.7
Unsaturated zone 1, soil density ^a	g/cm ³	Not used	1.35	1.35
Unsaturated zone 1, total porosity ^a	-	Not used	0.4	0.4
Unsaturated zone 1, effective porosity ^a	-	Not used	0.2	0.2
Unsaturated zone 1, soil-specific b parameter ^a	-	Not used	7.12	7.12
Unsaturated zone 1, hydraulic conductivity ^a	m/yr	Not used	200	200
Inhalation rate ^b	m ³ /yr	8,400	8,400	8,400
Mass loading for inhalation ^b	g/m ³	0.0002	0.0002	0.0002
Shielding factor, inhalation ^b	-	0.4	0.4	0.4
Shielding factor, external gamma ^b	-	0.7	0.7	0.7
Time fraction, indoors ^a	-	0.057	0	0.5
Time fraction, outdoors ^a	-	0.171	0.086	0.25
Shape factor, external gamma ^b	-	1	1	1
Dilution length for airborne dust, inhalation ^b	m	3	3	3
Fruit, vegetable, and grain consumption ^b	kg/yr	Not used	Not used	160.0
Leafy vegetable consumption ^b	kg/yr	Not used	Not used	14.0
Milk consumption ^b	L/yr	Not used	Not used	92.0
Meat and poultry consumption ^b	kg/yr	Not used	Not used	63
Fish consumption ^b	kg/yr	Not used	5.4	5.4
Other seafood consumption ^b	kg/yr	Not used	0.9	0.9
Soil ingestion ^b	g/yr	36.5	36.5	36.5
Drinking water intake ^b	L/yr	Not used	510	510
Fraction of drinking water from site ^b	-	Not used	0.01	1.0
Fraction of aquatic food from site ^b	-	Not used	0.05	0.5
Livestock fodder intake for meat ^b	kg/d	Not used	Not used	68.0
Livestock fodder intake for milk ^b	kg/d	Not used	Not used	55.0
Livestock water intake for meat ^b	L/d	Not used	Not used	50.0
Livestock water intake for milk ^b	L/d	Not used	Not used	160.0
Mass loading for foliar deposition ^b	g/m ³	Not used	Not used	0.0001
Depth of soil mixing layer ^b	m	0.15	0.15	0.15
Depth of roots ^b	m	Not used	Not used	0.9
Groundwater fractional usage (balance from surface water):				
Drinking water ^a		Not used	1.0	1.0
Livestock water ^a		Not used	Not used	1.0
Irrigation ^a		Not used	Not used	1.0

TABLE A-1. (contd)

Parameter	Unit	Value		
		Scenario 1	Scenario 2	Scenario 3
Total porosity of the cover material ^b	-	Not used	Not used	Not used
Total porosity of the house or building foundation ^b	-	Not used	Not used	Not used
Volumetric water content of the cover material ^b	-	Not used	Not used	Not used
Volumetric water content of the foundation ^b	-	Not used	Not used	Not used
Diffusion coefficient for radon gas:	m/s			
In cover material ^b		Not used	Not used	Not used
In foundation material ^b		Not used	Not used	Not used
In contaminated zone soil ^b		Not used	Not used	Not used
Emanating power of radon-222 ^b	-	Not used	Not used	Not used
Emanating power of radon-220 ^b	-	Not used	Not used	Not used
Radon vertical dimension of mixing ^b	m	Not used	Not used	Not used
Average annual wind speed ^b	m/s	Not used	Not used	Not used
Average building air exchange rate ^b	h ⁻¹	Not used	Not used	Not used
Height of building (room) ^b	m	Not used	Not used	Not used
Building indoor area factor ^b	-	Not used	Not used	Not used
Bulk density of house or building foundation ^b	g/cm ³	Not used	Not used	Not used
Thickness of house or building foundation ^b	m	Not used	Not used	Not used
Building depth below ground surface ^b	m	Not used	Not used	Not used

^a Values based on site specifications or scenario assumptions.

^b RESRAD default values.

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