6.0 Radiation Dose

> **Results in Brief: 2008 Estimated Doses**
>
> **Airborne Emissions**—The estimated maximum effective dose equivalent at the site boundary from 2008 airborne emissions (excluding radon) was 0.017 mrem/yr (0.00017 mSv/yr), which is 0.17 percent of the EPA NESHAP 10-mrem/yr dose limit.
>
> **Direct Radiation**—The estimated 2008 effective dose equivalent at the northeastern boundary of the site was 6 mrem/yr (0.06 [mSv/yr). This is 6 percent of the 100-mrem/yr (1-mSv/yr) DOE limit.
>
> **Dose to the Maximally Exposed Individual**—The dose to the MEI for 2008 was estimated to be 6 mrem/yr (0.06 mSv/yr) at the northeastern boundary of the site. This is 6 percent of the 100-mrem/yr (1-mSv/yr) DOE limit.

This chapter provides the estimated 2008 dose to the public from air and direct radiation pathways and to aquatic organisms from remedial actions associated with the groundwater restoration program. EPA NESHAP regulations require the Fernald Preserve to demonstrate that the site's radionuclide airborne emissions are low enough to ensure that no one in the public receives an effective dose of 10 mrem/yr (0.1 mSv/yr) or more. Moreover, to determine whether the Fernald Preserve is in compliance with the DOE effective dose limit of 100 mrem/yr (1 mSv/yr) from all exposure pathways (excluding radon), estimates of dose due to direct radiation are combined with airborne emissions to estimate the total dose to the maximally exposed individual. This estimate reflects the incremental dose above background that is attributable to the site.

The DOE limits for radon and its decay products in air are provided in terms of concentrations rather than dose limits and are addressed independently of the all-pathway dose limit. A concentration-based limit is used because dose calculations associated with radon and its decay products are highly sensitive to assumed exposure parameters, which are difficult to confirm with environmental measurements. However, dose estimates for radon have been included in response to public interest in radon exposures. A number of accepted calculations are presented to demonstrate the variation of radon doses as a function of each calculation method. The radon dose estimates in this chapter can also be compared with radon dose estimates presented in previous annual Site Environmental Reports and other radon dose studies, such as the Fernald Dosimetry Reconstruction Project (RAC 1996).

This chapter also provides an assessment of dose to aquatic organisms that may be affected by the site's effluent to nearby streams and rivers. An assessment of dose to biota (i.e., aquatic and terrestrial organisms) is one of the requirements of DOE Order 5400.5. By limiting the dose to aquatic organisms, DOE Order 5400.5 seeks to limit the severity and likelihood of off-site environmental impacts attributable to the aquifer restoration effort at the Fernald Preserve. The dose assessment to biota is performed through the use of a computer model that estimates dose from measured radionuclide concentrations in effluent discharged to the Great Miami River.

6.1 Estimated Dose from Airborne Emissions

The estimated dose from 2008 airborne emissions was calculated from annual average radionuclide concentrations measured at the six air particulate monitoring locations (one background and five site boundary locations; Figure 5–1 shows the locations of the air particulate monitoring locations). The annual average background concentration was subtracted from the boundary concentrations to derive the net annual average concentration for each airborne radionuclide. Dose estimates were determined by converting the net annual average radionuclide concentrations to doses using values listed in 40 CFR 61 (NESHAP) Subpart H, Appendix E, Table 2. Appendix D contains the detailed accounting.

The maximum effective dose at the site boundary from 2008 airborne emissions was estimated to be 0.017 mrem/yr (0.00017 mSv/yr) and occurred at AMS-8A along the northeastern boundary of the site. This dose estimate is based on the conservative assumption that a person remains outdoors at the AMS-8A location 24 hours a day for the entire year; the actual dose received by this receptor would be lower than 0.017 mrem/yr (0.00017 mSv/yr), because the nearest residence is located approximately 0.5 mile (0.8 km) downwind from AMS-8A. The 2008 maximum site boundary dose is slightly less than the 2007 value (0.023 mrem/yr [0.00023 mSv/yr]).

Figure 6−1 provides a comparison between the air-pathway doses at the background and maximum boundary locations with the annual NESHAP limit of 10 mrem/yr (0.1 mSv/yr). The background and maximum boundary doses shown on Figure 6−1 are due to the airborne concentration of radium, thorium, and uranium (radon is excluded from the annual NESHAP limit of 10 mrem/yr [0.1 mSv/yr]). The maximum air-pathway dose of 0.017 mrem/yr (0.00017 mSv/yr) is in addition to the background dose of 0.25 mrem/yr (0.0025 mSv/yr) and the maximum dose represents 0.17 percent of the annual NESHAP limit. Appendix D provides the estimated dose for each radionuclide at every boundary air monitor.

A collective effective dose provides an aggregate measure of the impact of airborne emissions from the Fernald Preserve to the population in the area. The collective effective dose from 2008 airborne emissions (excluding radon) to the population within 50 miles (80 km) of the Fernald Preserve was estimated to be 0.039 person-rem (0.00039 person-sievert [person-Sv]) for a population of 2.7 million. The collective effective population dose for all pathways (air and direct radiation) was estimated to be 0.058 person-rem (0.00058 person-Sv). For comparison, background radiation from the sun and naturally occurring radionuclides in the earth and food products delivered an estimated collective effective dose of 300,000 person-rem (3,000 person-Sv) to the population within 50 miles of the Fernald Preserve.

6.2 Direct Radiation Dose

Direct radiation dose to deep tissue is primarily the result of gamma and X-ray emissions from radionuclides. The largest historical source of direct radiation at the site was the waste materials stored in the silos. This and all other significant surface radiation sources were removed from the site in 2006. Remaining surface sources for radiation are soil, which contains radium, thorium, and uranium isotopes at activities that are below the FRLs established in the OU5 ROD, and small pieces of debris that are exposed by soil erosion.

In past years, an estimate of direct radiation dose was calculated for the resident living nearest the boundary TLD location with the highest measurement. This dose was estimated by using the net measurement at the TLD location and accounting for the distance between the boundary TLD location and the residence, which lowered the direct radiation dose because dose decreases with distance from the radiation source. The boundary fence was removed in late 2006, and direct radiation is now assessed at the monitor location, as there is no fence to prevent an individual from standing at this location. Calculation of dose at the monitor location accounts for the higher doses in 2007 and 2008, relative to dose reported in the 2006 Site Environmental Report.

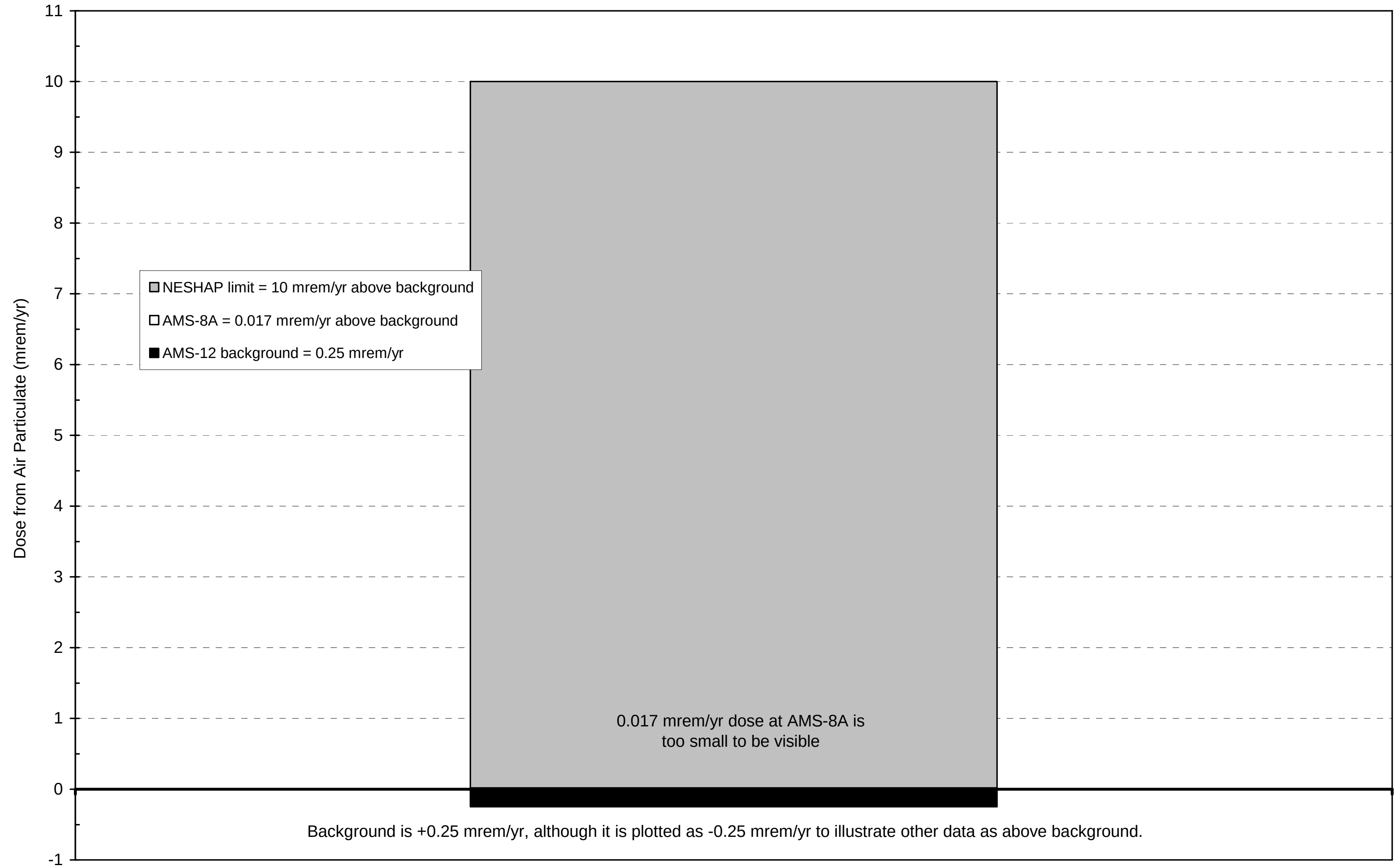

Figure 6–1. Comparison of 2008 Air-Pathway Doses and Allowable Limits

From the data in Table 5−3, the maximum boundary measurement is 54 mrem/yr (0.54 mSv/yr) at TLD location 8, and the background dose is 48 mrem/yr (0.48 mSv/yr). The difference in the TLD dose between location 8 and the background monitor is 6 mrem/yr (0.06 mSv/yr), which is assumed to be the direct radiation dose for a hypothetical individual who stands at location 8 for one year. This is a very conservative estimate of the dose, as an individual would not spend an entire year at location 8. Additionally, Appendix C, Attachment C.3 shows that the present measurements at the boundary are indistinguishable from background results when statistical variability is considered.

6.3 Total of Doses to the Maximally Exposed Individual

The MEI is the member of the public who receives the highest estimated effective dose based on the sum of the individual pathway doses. It is the maximum dose because the MEI is assumed to spend 24 hours a day, 365 days a year at the site boundary where maximum direct radiation and air dose are measured. As shown in Table 6−1, the 2008 dose to the MEI is 6 mrem/yr (0.06 mSv/yr) and represents the sum of the estimated doses from direct radiation and airborne emissions (excluding radon). The conservative assumptions used throughout the dose calculation process ensure that the dose to the MEI is the maximum possible dose any member of the public could receive.

Table 6–1. Dose to MEI

Pathway	Dose Attributable to the Fernald Preserve	Applicable Limit
Direct radiation at TLD-8	6 mrem/yr	100 mrem/yr (total for all pathways)
Airborne emissions at AMS-8A (excluding radon)	0.017 mrem/yr	10 mrem/yr (air pathway)
MEI[a]	6 mrem/yr	100 mrem/yr (total for all pathways)

[a]MEI is the sum of direct radiation and particulate.

The contributions to this all-pathway dose are:

- 6 mrem/yr (0.06 mSv/yr) from direct radiation to a receptor standing at TLD-8, located near the northeastern boundary of the site.
- 0.017 mrem/yr (0.00017 mSv/yr) from air inhalation dose to a receptor standing at AMS-8A, located near the northeastern boundary of the site.

The estimate represents the incremental dose above background attributable to the Fernald Preserve, exclusive of the dose received from radon. Figure 6−2 provides a comparison between the average background radiation dose at the background location (48 mrem/yr [0.48 mSv/yr]) and the dose to the MEI (6 mrem/yr [0.06 mSv/yr]), relative to the annual DOE limit (100 mrem/yr [1 mSv/yr]).

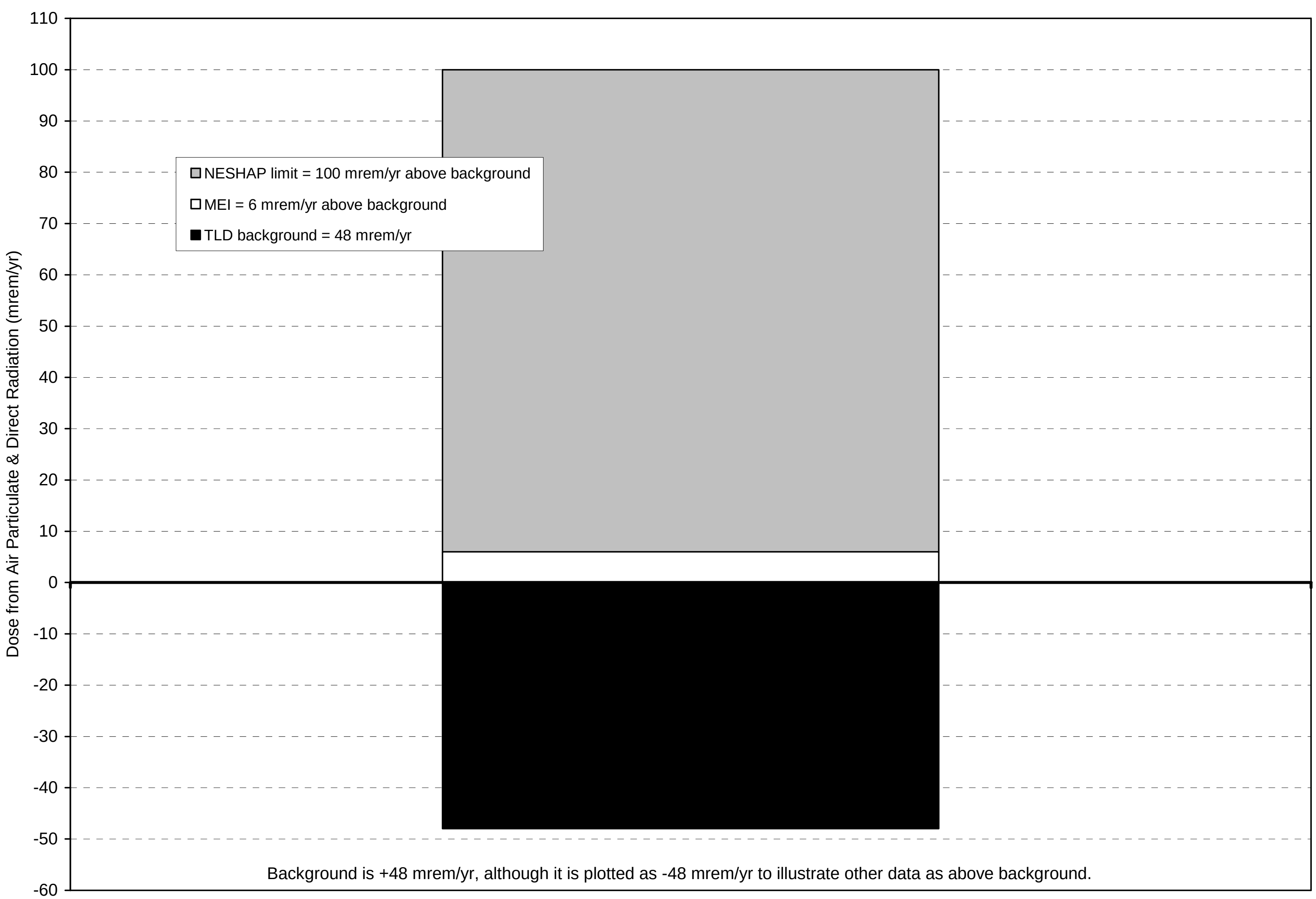

Figure 6–2. Comparison of 2008 All-Pathway Doses and Allowable Limits

6.4 Significance of Estimated Radiation Doses for 2008

One method of evaluating the significance of the estimated doses is to compare them with doses received from background radiation. Background radiation delivers an annual dose of approximately 100 mrem/yr (1 mSv/yr) from natural sources, excluding radon. For example, the dose received each year from cosmic and terrestrial background radiation contributes approximately 26 mrem/yr (0.26 mSv/yr) and 28 mrem/yr (0.28 mSv/yr), respectively. This sum (54 mrem/yr) is in close agreement with the direct radiation dose of 48 mrem/yr at the background location, and it is nine times greater than the 6-mrem/yr-above-background dose estimated for the individual at TLD location 8. The100 mrem/yr per person background also includes dose from the ingestion of food and medical X-rays (about 46 mrem/yr), which is not recorded by the direct radiation TLDs at the boundary and background locations. In addition, the background radiation dose will vary in different parts of the country. Living in the Cincinnati, Ohio, area contributes an annual dose of approximately 110 mrem/yr (1.1 mSv/yr), whereas living in Denver, Colorado, increases the background to approximately 125 mrem/yr (1.25 mSv/yr) (NAS 1980, NCRP 1987).

Another method of determining the significance of the estimated dose is to compare it with dose limits developed to protect the public. The International Commission on Radiological Protection (ICRP) has recommended that members of the public receive less than 100 mrem/yr (1 mSv/yr) above background. As a result of this recommendation, DOE has incorporated 100 mrem/yr (1 mSv/yr) above background as the limit in DOE Order 5400.5. The sum of all estimated doses from 2008 site operations (6 mrem/yr [0.06 mSv/yr], excluding radon) is considerably below this limit (Figure 6−2).

6.5 Estimated Dose from Radon

Radon decays to produce radioactive daughter products. Radon and its airborne daughter products attached to dust particles may be inhaled and deposited within the lungs. As radon and the daughter products decay, they emit charged particles (alpha and beta particles) that may damage sensitive tissues of the lung. For exposures to radon and its daughters, the target organ for the radiation dose is the lung.

Radon dose estimates from the ICRP and the National Council on Radiation Protection (NCRP) have been revised and updated over the years, and the net effect is a decrease in the estimated health damage per unit of radiation exposure. The revisions were based on reevaluations of studies that examine the detrimental health effects (e.g., epidemiological studies) on highly exposed worker populations (e.g., uranium miners). Therefore, radon dose estimates were generated for this report using the following four calculation methods:

- **Working-Level-Month (WLM) Determination—**Historically, exposure to radon and its daughters has been measured in the units of working levels, which is a measure of the activity of radon and its daughters in air. One working level is equivalent to an activity of 100 pCi/L of radon in 100 percent equilibrium with its daughters. An individual exposure is determined by multiplying the job-specific working level by the number of exposure hours and dividing this by 170 hours per month, yielding the exposure unit WLM. WLMs are provided in this annual report because this is the fundamental unit used by government agencies and private industries for all dose conversion factors and coefficients associated with estimating a dose from radon and its daughters.

- **National Council on Radiation Protection and Measurements, Report 78 (NCRP 1984)—**The NCRP 1984 document, in part, provides equations for converting exposure from inhalation of radon daughter products to an equivalent lung dose. The calculation considers the whole lung as the target organ for the radiation exposure. A number of dose conversion factors and assumptions are used to equate the lung dose to a whole body radiation dose (i.e., effective dose equivalent). Equations from this report were used in previous annual Site Environmental Reports and are presented here for direct comparison to estimates from previous years.
- **International Commission on Radiological Protection, Report 66 (ICRP 1994a) Tissue-Weighting Factor Modification to NCRP Report 78 Equation—**The ICRP 1994a report introduced a specific tissue-weighting factor representing the localized radiation exposure from radon and its daughters to the bronchial epithelium (a specific region of the lung thought to be the source for lung cancer). Using the ICRP weighting factor in the NCRP equations from Report 78 results in a reduction of the effective dose by a factor of three. This calculation allows comparison to dose estimates provided in the Fernald Dosimetry Reconstruction Project, as performed by Risk Assessments Corporation under contract with the Centers for Disease Control.
- **ICRP Report 65 (ICRP 1994b)—**This ICRP 1994b report presents a methodology for calculating radon dose using detriment coefficients for estimating dose from exposure to radon and its daughters. The coefficients are based on epidemiological studies of the lung cancer rates among uranium miners, and the use of these coefficients results in a dose conversion factor of approximately 500 mrem (5 mSv) per WLM.

Table 6−2 presents the 2008 radon dose estimates. Radon concentrations at the boundary and background locations, as well as DOE radon limits, are provided as the basis for the dose calculations. Rounding the dose estimates to one significant figure produces identical results for the background (0.3 pCi/L) and maximum boundary (0.2 pCi/L above background) locations. The estimated WLM exposures are given for each concentration value, assuming a radon daughter equilibrium concentration of 70 percent. Effective dose equivalents are calculated using the WLM results and the NCRP Report 78, ICRP Report 66, and ICRP Report 65 methods. All dose estimates are for a reference man of average body size and breathing rate who continuously breathes air at the site boundary while engaged in light, physical activity 24 hours a day for the entire year (i.e., 8,760 hours per year). The calculated dose to this maximally exposed reference man is very conservative, and the methodology of the ICRP Report 65 yields a 2008 dose of 50 mrem/yr (0.50 mSv/yr) above background at the site boundary, which is identical to the reported 2007 result.

As presented in Table 6−2, the maximum measured radon concentration and corresponding dose at the Fernald Preserve boundary are below the limits associated with proposed 10 CFR 834 and DOE Order 5400.5 (interim storage during remediation). Although there are no regulatory limits for dose from radon and its daughters, the radon concentration limits proposed by 10 CFR 834 and DOE Order 5400.5 provide a benchmark for evaluating the estimated doses from radon at the Fernald Preserve boundary. In 10 CFR 834 and DOE Order 5400.5, the annual average radon concentration limits at the facility boundary are 0.5 pCi/L and 3.0 pCi/L above background, respectively. Using the ICRP 65 methodology, these concentrations yield, respectively, an effective dose equivalent of 100 mrem/yr (1 mSv/yr) and 550 mrem/yr (5.5 mSv/yr).

Table 6–2. 2008 Radon Dose Estimate [a]

Location	Radon Concentration (pCi/L)	Exposure in WLMs[a]	NCRP Report 78 Effective Dose Equivalent Equation		ICRP Report 65 Effective Dose Equivalent (mrem)[d]
			(mrem)[b]	(mrem)[c]	
Background	0.3	0.1	200	70	50
Maximum Boundary (net, above background)	0.2	0.1	200	70	50
10 CFR 834 Limit (net, above background)	0.5	0.2	400	140	100
DOE Order 5400.5 Limit (net, above background)	3.0	1.1	2,200	770	550

[a]Assuming the suggested environmental radon daughter equilibrium concentration of 70 percent.
[b]NCRP Report 78 (NCRP 1984) suggests whole lung tissue weighting factor of 0.12.
[c]NCRP Report 78 calculation using the ICRP Report 66 (ICRP 1994a) bronchial epithelium weighting factor of 0.04.
[d]Using the dose conversion factor for the maximally exposed reference person (ICRP 1994b).

6.6 Estimated Dose to Biota

DOE Order 5400.5 requires that populations of aquatic biota be protected at a dose limit of 1 rad/day (10 milligray per day [mGy/day]). DOE has issued a technical standard entitled *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002b) and supporting software (RAD-BCG) for use in the evaluation and reporting of biota dose limits.

In general, the dose and compliance assessment process involves comparing radionuclide concentrations measured in surface water or sediment samples to biota concentration guides (BCGs) established by researchers. The BCGs are set so that biota exposed at the BCG level would not be expected to exceed the biota dose limit of 1 rad/day (10 mGy/day) during a calendar year. The measured radionuclide concentration in water or sediment is divided by the appropriate BCG value, and if the resulting fraction is less than 1.0, compliance with the biota dose limit is demonstrated for that nuclide. BCGs have been established for radionuclides that are relatively common constituents in past releases to the environment from DOE facilities. At facilities such as the Fernald Preserve, where multiple contaminants (e.g., radium, thorium, and uranium) can be released, a “sum-of-the-fractions” rule applies. The sum-of-the-fractions rule means each radionuclide fraction (i.e., the measured concentration divided by the BCG for that nuclide) must be summed, and the sum of all nuclide fractions must be less than 1.0.

For 2008, compliance with the dose limit to aquatic biota was determined by using the maximum concentration of each radionuclide found in Paddys Run at Willey Road (SWP-03) and effluent discharged from the Parshall Flume (PF4001) to the Great Miami River (refer to Chapter 4). The maximum concentration in water delivered from the Parshall Flume and Paddys Run is multiplied by the annual volume of water discharged from the Parshall Flume and Paddys Run to obtain a net mass for each nuclide delivered to the Great Miami River. The net mass is divided by the sum of the discharge volumes and low-flow volume from the Great Miami River to derive input concentrations to the RAD-BCG computer model. The results of this assessment indicate that the sum of the fractions for radium, technetium, thorium, and uranium isotopes is 0.010, which is well below the compliance threshold value of 1.0. Appendix C, Attachment C.5 provides additional information on the biota dose assessment.

This page intentionally left blank