6 Dose

Abstract

For 2004, exposure pathways potentially contributing to dose were determined to include ingestion of surface water, ingestion of sediments, ingestion of deer meat, direct radiation, and atmospheric releases. The highest estimated dose a maximally exposed individual might have received from all combined DOE exposure pathways (worst-case scenario) was 0.359 mrem. This dose is less than 5 percent of the applicable federal standard of 100 mrem per year.

Introduction

This section presents the calculated doses to individuals and the surrounding population from atmospheric and liquid releases from the Paducah Site, as well as direct radiation (sections 4 and 5). In addition, potential doses from special-case exposure scenarios, such as deer meat consumption, were calculated based upon deer sample analyses. Doses from naturally occurring sources are discussed in Appendix A. The highest estimated dose a maximally exposed individual might have received from all combined DOE exposure pathways (worst-case scenario) was 0.359 mrem. This dose is less than five percent of the applicable federal standard of 100 mrem per year.

U.S. Department of Energy Order 5400.5, *Radiation Protection of the Public and the Environment*, limits the dose to members of the public to less than 100 mrem per year total effective dose equivalent from all pathways resulting from operation of a DOE facility. Information on the demography and land use of the area surrounding the plant and identification of on-site sources have indicated radionuclides and exposure pathways of concern.

For the Phase I Remedial Action SI, a preliminary assessment of risk to public health from contaminants at the Paducah Site was conducted. This study identified the following four primary pathways that each could contribute greater than 1 percent to the total off-site dose: (1) groundwater ingestion, (2) sediment ingestion, (3) wildlife ingestion, and (4) exposure to direct radiation. Since that preliminary assessment, groundwater wells that supplied drinking water in the downgradient direction from PGDP have been replaced with public drinking water, resulting in the loss of that pathway. Surface water is not considered to be the primary pathway for water ingestion. In addition, the NWPGS began operation in 1995, resulting in an airborne pathway that is now included in the dose calculations. In 2004, the Scrap Metal Removal Projects and the C-410 D&D activities also were added to the airborne dose. Furthermore, in 1999, a drinking water pathway was added for consumption of surface water at the nearest public drinking water source [Ohio River at Cairo, Illinois (L306)].

To fully assess the potential dose to the public, a hypothetical group of extreme characteristics was used to postulate an upper limit to the dose of any

real group. This is referred to as the worst-case scenario. The actual dose received is likely to be considerably less than the dose calculated.

Terminology and Internal Dose Factors

Most consequences associated with radionuclides released to the environment are caused by interactions between human tissue and various types of radiation emitted by the radionuclides. These interactions involve the transfer of energy from radiation to tissue and possibly resulting in tissue damage. Radiation may come from radionuclides outside the body or from radionuclides deposited inside the body (by inhalation, ingestion, and, in a few cases, absorption through the skin). Exposures to radiation from radionuclides outside the body are called external exposures; exposures to radiation from radionuclides inside the body are called internal exposures. This distinction is important because external exposure occurs only as long as a person is near the external radionuclide; simply leaving the area of the source will stop the exposure. Internal exposure continues as long as the radionuclide remains inside the body.

A number of specialized terms or quantities have been defined for characterizing exposures to radiation as defined in Appendix A. Because the damage associated with such exposures results primarily from the deposition of radiant energy in tissue, the exposure is defined in terms of the amount of incident-radiant energy absorbed by tissue and the biological consequences of that absorbed energy. These terms or quantities include the following:

- *Committed effective dose equivalent (CEDE)*—the total internal dose (measured in mrem) received over a 50-year period resulting from the intake of radionuclides in a one-year period. The CEDE is the product of the annual intake (pCi) and the dose conversion factor for each radionuclide (mrem/pCi).
- *Effective dose equivalent*—includes the CEDE from internal deposition of radionuclides and the dose from penetrating radiation from sources external to the body. This is a risk-equivalent value and can be used to estimate the health-effects risk to the exposed individual.
- *Total effective dose equivalent*—includes the sum of the effective dose equivalent (for external exposures) and the CEDE (for internal exposures). For purposes of compliance, dose equivalent to the whole body may be used as the effective dose equivalent for external exposures.

Internal dose factors for several radionuclides of interest at the Paducah Site are included in Appendix A.

Direct Radiation

In 2004, DOE conducted continuous monitoring for direct external radiation exposure (Section 5). Access to PGDP is limited due to the increased security boundary implemented in September 2001. The monitoring results indicate that, due to limited access of the public to radioactive source areas, the dose to the maximally exposed individual member of the public (i.e., the neighbor living closest to the PGDP security fence) from DOE operations did not vary statistically from background (i.e., zero) (BJC 2005b).

For purposes of this ASER, an additional potential receptor was considered. In a conservative exposure scenario, this receptor is assumed to be exposed to the location at TLD-14 for 8.3 hours for the year. The 8.3 hours-per-year assumption is based on an individual driving past this location twice per day at 1 minute per trip, five days per week, 50 weeks per year. It is likely that actual exposure at this location is probably much less than assumed because any shielding from the receptor's vehicle is not considered. The closest location that would be accessible to the public in 2004 was TLD-14, which is near Harmony Cemetery located north of the plant security fence and south of Ogden Landing Road (Figure 5.6). This location resulted in external radiation exposures below background. Based on results from this location and other data obtained from all locations, the dose to the maximally exposed individual member of the public from DOE operations was zero.

Surface Water

The most common surface-water pathway for exposure is through drinking water containing radionuclides. Surface-water pathway dose was calculated for an individual assumed to consume water from the public drinking water supply at Cairo, Illinois (L306). Cairo is the closest drinking water

system (approximately 30 miles downstream) that uses water downstream of PGDP effluents. Typically, the average concentrations of radionuclides that were detected in Cairo are used to calculate the exposure resulting from consumption of surface water. In 2004, there were no radionuclides detected at the Cairo location. Therefore, the resulting net exposure to the maximally exposed receptor from the Paducah Site is 0.00 mrem.

Contaminated Sediment

Exposure to contaminated sediment in Bayou Creek and Little Bayou Creek could occur during fishing, hunting, or other recreational activities. Exposure is possible through incidental ingestion of contaminated sediment. The worst-case ingestion assumption is that an individual would splash around in one of the creeks every other day during the hunting season and ingest a small amount of sediment each visit (50 mg/day). A dose is then calculated based on the radionuclide concentrations and the amount of exposure via ingestion. Massac Creek samples are assumed to be background and are subtracted from downstream-sample results to arrive at a dose associated with site releases. The downstream location with the maximum dose is assumed to represent the dose received from this pathway by the maximally exposed individual.

Doses are calculated for ingestion of sediments for both Bayou Creek and Little Bayou Creek. The worst-case dose was calculated to be at S32, the NSDD (Figure 5.3). The estimated worst-case dose above background from sediment ingestion was 0.359 mrem in 2004. This exposure pathway is by far the major contributor to the worst-case combined exposure to the public and it is significantly less than the DOE annual dose limit of 100 mrem/year. Sediment sample locations were shown in Figure 5.4. Dose results for all locations are provided in Table 6.1.

Ingestion of Deer

The effect of an intake of a radionuclide by ingestion depends on the concentration of the radionuclide in food and drinking water and on the individual's consumption patterns. The estimated intake of a radionuclide is multiplied by the appropriate ingestion dose factor to provide the estimate of CEDE resulting from the intake.

Terrestrial wildlife, such as deer, can come into contact with contaminated soil, ingest plants that have taken up contaminants, or ingest contaminated water. Hunting is permitted in the WKWMA surrounding the Paducah Site, and the limit for deer harvest is two deer per person per season. Approximately 100 deer are harvested per year from WKWMA. The Paducah Site dose calculations assume that an individual kills two average-weight deer and consumes the edible portions of those deer during the year (approximately 100 pounds of meat and five pounds of liver). The dose is calculated for each deer sampled.

In 2004, five deer from the Paducah Site were sampled. No reference deer was collected in 2004; therefore, 2002 data were used for comparison. In 2004, the results of the site deer did not vary significantly from the background deer values. Therefore, the site dose contribution is essentially 0 mrem (Hampshire 2005). This is less than the 1.5 mrem calculated in 2003.

Airborne Radionuclides

The DOE's radionuclide airborne point-sources that contributed to the public dose in 2004 included three sources. These sources were the NWPGS, the Scrap Metal Removal Projects, and the C-410 D&D Fluorine Cell Blasting Project. The three point-sources were discussed in Section 4. These point-sources were reviewed or monitored to determine the extent to which the general public could be exposed and to demonstrate compliance with EPA regulations that are based on International Commission on Radiological Protection (ICRP) publications (ICRP 1980).

The 50-year CEDE (internal) from DOE air sources to the maximally exposed individual, who under most circumstances is the person living closest to the plant in the predominant wind direction, is calculated each year. Environmental Protection Agency-supplied CAP-88 software was used to calculate the off-site dose from PGDP air emissions. This software provides a framework for developing dose and risk assessments for the purpose of demonstrating compliance with 40 C.F.R. 61.93(a). It assesses both collective populations and maximally exposed individuals. The dose to the maximally exposed individual from DOE radioactive air emissions was calculated to be 1.8 x 10^{-5} mrem from the NWPGS; 2.2 x10^{-4} mrem from

Table 6.1 Annual dose estimates for 2004 incidental ingestion of sediment from Bayou Creek and Little Bayou Creek

Location	Committed Effective Dose Equivalent (mrem)										Total (mrem)
	^{241}Am	^{137}Cs	^{237}Np	$^{239/240}$Pu	^{40}K	^{99}Tc	^{230}Th	^{234}U	^{235}U	^{238}U	
S1	---	9.0E-06	1.5E-03	3.5E-04	2.8E-04	2.7E-05	7.9E-04	2.1E-03	5.7E-04	3.1E-03	8.8E-03
S2	---	1.3E-05	---	---	4.3E-04	2.1E-06	5.9E-04	1.8E-03	3.3E-04	1.4E-02	1.8E-02
S20	---	5.6E-06	---	---	3.9E-04	---	5.1E-04	1.4E-04	---	1.2E-04	1.2E-03
S21	---	---	---	---	4.0E-04	1.3E-06	9.6E-04	2.0E-04	---	2.3E-04	1.8E-03
S27	4.6E-04	8.9E-06	---	9.4E-04	4.3E-04	4.0E-06	2.3E-03	6.7E-04	5.7E-04	2.4E-03	7.8E-03
S28 (Background)	---	---	---	---	3.8E-04	---	4.4E-04	1.1E-04	---	1.0E-04	1.0E-03
S30	---	---	---	---	4.4E-04	---	7.9E-04	---	0.0E+00	---	1.2E-03
S31	---	8.6E-06	---	6.3E-04	3.1E-04	2.0E-06	1.6E-03	1.1E-03	1.3E-03	6.4E-04	5.6E-03
S32 (Maximum)	2.8E-02	2.6E-04	2.5E-02	8.7E-02	7.2E-04	2.8E-04	2.0E-01	7.2E-03	7.8E-04	9.5E-03	3.6E-01
S33	---	8.8E-06	---	---	5.9E-04	2.0E-06	6.9E-04	6.7E-04	9.7E-04	6.7E-04	3.6E-03
S34	3.5E-03	1.2E-05	3.6E-04	2.8E-03	4.1E-04	1.1E-05	6.4E-03	7.1E-04	5.8E-04	2.0E-03	1.7E-02
C612	0.0E+00	1.8E-05	2.3E-03	8.4E-04	6.9E-04	8.0E-05	1.5E-03	2.7E-03	8.3E-04	3.7E-03	1.3E-02
C616	7.7E-04	3.7E-05	4.5E-03	2.6E-03	8.7E-04	1.6E-04	2.3E-03	7.0E-03	8.4E-04	8.1E-03	2.7E-02
C746KTB2	---	5.2E-06	---	---	3.4E-04	3.4E-06	6.7E-04	1.6E-04	---	1.1E-04	1.3E-03
C746KUP	---	9.8E-06	---	1.7E-04	5.1E-04	1.4E-06	5.4E-04	3.3E-04	9.1E-04	3.6E-04	2.8E-03
K001	---	8.7E-06	4.0E-04	5.1E-04	6.1E-04	1.8E-05	1.1E-03	1.3E-03	8.7E-04	1.8E-03	6.7E-03
	[a]Net exposure from Paducah Site to maximally exposed individual (S32—S28) =										**3.59e-1**

--- nondetect
^{241}Am Americium-241
$^{239/240}$Pu Plutonium-239/240
^{40}K Potassium-40

[a]Maximum allowable exposure is 100 mrem/year for all contributing pathways (DOE Order 5400.5).

the Scrap Metal Removal Projects; and 1.1 x 10^{-7} mrem from the C-410 D&D Activities. If an individual was to receive the maximum dose from each of these sources, it would add up to approximately 0.00024 mrem, which is well below the 10 mrem limit of 40 C.F.R. Part 61, Subpart H.

Conclusions

Table 6.2 provides a summary of the dose for 2004 from the Paducah Site that could be received by a member of the public assuming worst-case exposure from all major pathways. The largest contributor to the calculated dose is from ingestion of sediment. The groundwater pathway from DOE sources is assumed to contribute no dose to the population because all residents have been supplied with public water by DOE. The worst-case combined (internal and external) dose to an individual member of the public was calculated at 0.359 mrem. This level is well below the DOE annual dose limit of 100 mrem/year to members of the public and below the EPA limit of 10 mrem airborne dose to the public.

Estimates of radiation doses presented in this report were calculated using the dose factors provided by DOE and EPA guidance documents. These dose factors are based on ICRP Publication 30 (ICRP 1980). Figure 6.1 shows the potential (worst-case) annual dose as calculated for the past five years.

Table 6.2 Summary of potential radiological dose from the Paducah Site for 2004 (worst-case combined exposure pathways)

	Dose[a] (mrem/year)	Percent of total
Ingestion of surface water	0	0
Ingestion of sediments	0.359	99.94
Ingestion of deer meat	0	0
Direct radiation	0	0
Atmospheric releases[b]	2.4×10^{-4}	0.06
Total annual dose above background (all pathways)	**0.359**	**100**

[a] Maximum allowable exposure is 100 mrem/year (DOE Order 5400.5).

[b] DOE source emissions were from the NWPGS, the Scrap Metal Removal Projects, and the C-410 D&D Fluorine Cell Blasting Activities.

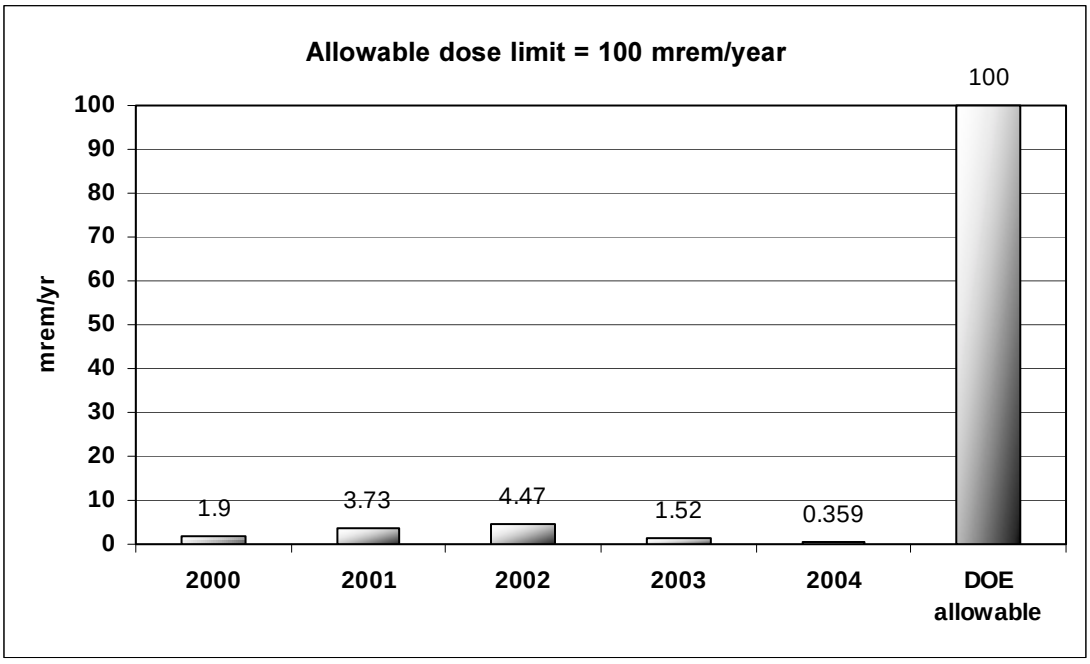

Figure 6.1 Potential radiological dose from DOE activities at the Paducah Site, 2000–2004