

3.0 DOE INVENTORIES

This chapter provides information on inventories of potentially clearable materials from U.S. Department of Energy facilities. In 2000, DOE estimated that ferrous metals currently in scrap yards within the DOE complex plus ferrous metals expected from dismantling of obsolete facilities will amount to about one million tons. Approximately 60 percent of this metal is associated with the gaseous diffusion plants at Oak Ridge (K-25 Site), Portsmouth and Paducah. Decontamination and decommissioning (D&D) is in progress at the K-25 Site. Based on limited frequency distributions of metal surface assays, estimates are made in this chapter of the incremental quantities of ferrous metals associated with specific surface radioactivity levels. Approximately 78 percent of the 511,000 tons of ferrous metals from D&D of the diffusion plants would have an activity of less than 4,400 Bq/kg (120 pCi/g). Copper and aluminum are also characterized from more limited data. Radioactivity levels in 59,000 tons of aluminum were estimated to range from 14,600 to 63,600 Bq/kg (394 to 1,718 pCi/g) for a mixture of radionuclides, including Tc-99, U-238, Pu-239, and Np-237. Slightly lower radioactivity levels were estimated for copper. Data were insufficient to characterize concrete radioactivity levels in the diffusion plants. Information in the published literature was insufficient to quantitatively characterize DOE facilities other than the gaseous diffusion plants.

This section provides information on the current and projected inventories of potentially clearable materials from U.S. Department of Energy (DOE) facilities. Section 3.1 discusses complex-wide (all DOE facilities) estimates of materials in inventory and materials expected to be generated by future decontamination and decommissioning activities (D&D). Section 3.2 discusses materials from the gaseous diffusion plants. Section 3.3 discusses potentially clearable materials from other DOE sites. Section 3.4 describes how the data were compiled and analyzed for use in the collective dose and cost analyses.

Previous complex-wide DOE studies on scrap metals focused on materials in inventory. More recently DOE has developed a complex-wide estimate of ferrous metals and nickel in inventory and expected from D&D through 2035. Estimated total quantities of ferrous metals are about one million tons. Information is generally lacking on the kinds and amounts of radioactivity associated with the various components of the total mass of potentially clearable materials. However, a more complete data set is available on the quantities of materials and the associated kinds and amounts of radioactivity found in the three gaseous diffusion plants (GDPs). Based on the most recent DOE survey, the metals in inventory and expected from the D&D of the diffusion plants comprise about 57 percent of the complex-wide metals. Consequently, the focus of the analysis presented in Section 3.4 is on materials from the GDPs. Lack of published data on the kinds and amounts of radioactivity associated with other DOE facilities has precluded any

meaningful quantitative analysis regarding clearance of scrap metals from these other facilities. While it is possible to distribute measured radioactivity from a limited subset of facilities over the cumulative mass of a given type of metal, sufficient information is not available to distribute the measured radioactivity over specific components or scrap metal items.

3.1 Complex-Wide Inventories

The quantities of materials in inventory and expected from future D&D operations have been reviewed in numerous papers over the last several years. More attention was focused on materials in inventory than on materials generated from D&D activities. In either case, the reported quantities vary widely. This is, in large measure, due to two problems:

- Although certain specific elements of the current inventory are reasonably well characterized, globally the underlying quality of the data, particularly when addressing future D&D, is poor. Characterization is not uniform from site to site.
- The context in which the inventory data are quoted varies depending on the needs and perspectives of the authors of each report.

With regard to the second problem, some authors may include the material contained at all facilities regardless of whether it is likely to be buried or “rubble-ized” waste; others may address materials that can be recycled within DOE for waste containers or shielding blocks; still others may include materials that can only be cleared and recycled with aggressive and perhaps non-cost-effective decontamination techniques; and some may add suspect contaminated material, which is probably clearable, but has not yet been evaluated to quantify such an assumption.

In 1995, SC&A concluded that DOE inventories of radioactive scrap metal were 154,000 tons (SC&A 1995a). In a subsequent 1995 SC&A report (SC&A 1995b), which contained updated information and sites not included in SC&A 1995a, it was estimated that the DOE inventory of radioactive scrap metal was 207,000 tons. In the latter report, SC&A estimated that about 1 million tons of radioactive scrap metal would be generated from D&D operations. About 70 percent of this scrap metal was estimated to be generated during D&D of the three gaseous diffusion plants. Another 7 percent was carbon steel associated with the cooling water holdup tanks and holdup tank piping for the Hanford production reactors. The 1995 SC&A studies did not consider materials that were potentially clearable, but rather the total inventory of all materials including those likely to be too contaminated for clearance.

At about the same time, DOE published two complex-wide summary reports describing materials in inventory. These included the 1995 MIN Report (DOE 1995a, DOE 1996) and 1995 HAZWRAP or Parsons Report (Parsons et al. 1995). Results contained in these reports are presented in Sections 3.1.1 and 3.1.2. Neither of these reports considered concrete or the generation of materials from future D&D operations.

DOE presented a baseline environmental report to Congress in 1996 (DOE 1996b). In that report, DOE stated that all mission-related environmental management activities would be completed by 2070, but 90 percent of the life-cycle costs would be incurred by 2037. All decommissioning activities (which could generate potentially clearable materials) would be completed by about 2050. DOE estimated that the environmental restoration program would generate 2.4 million m³ of metals and 3.1 million m³ of rubble and debris. No indication is provided as to the potentially clearable materials within these waste categories.

An update on DOE inventories and projections of materials from future D&D operations was prepared by M.J. Gresalfi in 1997 (Gresalfi 1997).

In 1998 DOE estimated that the scrap metal available from inventory plus clean-up will exceed 1 million tons, with the following breakdown by site (DOE 1998a):

- Oak Ridge Sites: 894,500 tons
- INEEL: 71,500 tons
- Hanford: 72,900 tons
- LANL: 73,400 tons
- Rocky Flats: 97,000 tons
- SRS: 84,500 tons
- Weldon Spring: listed but not specified (apparently small)
- Pinellas: listed but not specified (apparently small)

DOE cited the sources for this information as a 1991 Ebasco report (for the gaseous diffusion plants) and Parsons et al. 1995. Obviously, other sources must have been used to supplement the referenced reports since D&D estimates are not included in either document except for the Oak Ridge sites.

In a 1999 report, Florida International University stated that DOE must decontaminate and decommission 1,200 buildings and dispose of 600,000 tons of metal and 23 million m³ of concrete, but the source of these values was not provided (Ebadian and Lagos 1999).

In the fall of 2000, DOE made a data call to major field locations to develop updated information on materials in inventory plus those expected from D&D. Results of this survey are discussed in Section 3.1.3.

3.1.1 The DOE Materials in Inventory (MIN) Initiative

In July 1994, DOE initiated a complex-wide survey to define the quantities of materials “not currently in use.” Materials embraced by this definition include materials on hand at DOE sites that had not been used for one year and were not expected to be used within the following year. One of the ten categories of materials selected for study was scrap metal and equipment. Items excluded from the scrap metal and equipment category were:

- Materials already designated as waste
- Materials set aside as strategic reserves
- Scrap metal buried as waste
- Structural metals that are part of buildings not yet decommissioned
- Scrap metal that is declared excess and is disposed of yearly (or more frequently)

The results of the MIN study provide a snapshot of DOE scrap metal inventories as of mid-1995. The inventory includes both clean and contaminated scrap metal. Equipment in the MIN study is defined as all equipment used for construction, production, or manufacturing and all associated spare parts and hand tools. Excluded from the equipment category are office equipment, consumables, items already declared excess by property management, and certain high-risk items (DOE 1995a). The MIN study did not consider scrap metals likely to be developed from future D&D activities.

The MIN study identified the quantities of scrap metal summarized in Table 3-1 (DOE 1996, Table 2-8). This material was characterized as “worn or superfluous metal parts or pieces, material found in storage and lay-down yards, and material generated by decommissioning buildings and facility maintenance and renovation.”

A breakdown of the scrap metal by type and contamination is presented in Table 3-2 (DOE 1996, Table 2-9). From Table 3-2, it is apparent that most (73 percent) of the scrap metal inventory was not characterized as to whether it has radioactivity.

Table 3-1. DOE Scrap Metal Inventory by Location (Mid-1995)⁸

| Site | Quantity (tons) |
|------------|--------------------|
| ANL-W | 26 |
| BNL | 662 |
| Fermilab | 6,760 |
| Fernald | 5,115 |
| Hanford | 2,516 ^a |
| INEEL | 2,300 |
| K-25 | 36,699 |
| LBL | 168 |
| NTS | 331 |
| ORNL | 1,411 |
| PGDP | 60,473 |
| Pantex | 290 |
| Portsmouth | 11,143 |
| RMI | 70 |
| SLAC | 17 |
| SRS | 15,533 |
| WIPP | 103 |
| Y-12 | 11,332 |
| Total | 154,949 |

a Of this, 2,100 tons is clean scrap, which is the average annual total sold to a scrap dealer.

Table 3-2 does not include the following items that are in Table 3-1: Hanford - 2,516 tons; LBL - 168 tons; and other sites - 350 tons.⁹

⁸ Although no data for RFETS are included in Table 2-8 of DOE 1996, the supporting document (DOE 1995) indicated that a total of 11 tons/month is on site at any time. If this inventory turns over monthly, the annual total would be 132 tons. Inclusion of this would be consistent with including 2,100 tons of annual scrap metals sales for Hanford. Although inclusion of the Hanford data appears to be inconsistent with the reporting guidelines set by DOE, the quantity is small, contributing slightly more than 1 percent to the total.

⁹ The reason given in DOE 1996 is that a breakdown of metal by type was not available. It is not clear why these metals could not have been listed as "Miscellaneous" and "Unspecified." In addition, there is an error in DOE 1996, Table 2-9 (the source for Table 3-2). The unspecified column in Table 2-9 is overstated by 3,034 tons. It is believed, based on information in DOE 1995a, that Miscellaneous, Unspecified is an erroneous entry. This value has been adjusted in Table 3-2 to reconcile the totals.

Table 3-2. DOE Scrap Metal Inventory by Metal Type and Radioactivity Levels
(Mid-1995)

| Metal Type | Clean (tons) | Contaminated (tons) | Unspecified (tons) | Total (tons) |
|------------------|-----------------|------------------------|-----------------------|-----------------|
| Carbon Steel | 1,109 | 12,582 | 103,929 | 117,620 |
| Nickel | 0 | 9,350 | 0 | 9,350 |
| Stainless Steel | 1,579 | 5,932 | 1,055 | 8,566 |
| Aluminum | 30 | 15 | 6,201 | 6,246 |
| Copper and Brass | 26 | 1,632 | 162 | 1,820 |
| Tin and Iron | 250 | 0 | 0 | 250 |
| Miscellaneous | 860 | 7,192 | 11 | 8,063 |
| Total Tons | 3,854 | 36,703 | 111,358 | 151,915 |
| Percent | 3 | 24 | 73 | 100 |

The MIN study provides very little information on radioactivity levels. Most of the unspecified material (i.e., 90 percent) is from the three gaseous diffusion plants, where the suspect radionuclides have been identified as uranium isotopes and progeny, Tc-99, and traces of Pu-239 and Np-237. Contamination at the gaseous diffusion plants is discussed in more detail in Section 3.2.2. Concerning the contaminated material in Table 3-2, comments on the source and type of contamination are noted below (DOE 1995a):

- Carbon steel:
 - 9,342 tons (SRS): contamination is generically identified as tritium, cobalt, europium, Cs-137, Am-241, Sb-125 and other beta emitters
 - 3,240 tons (Fernald): no contamination information in MIN study; principal contamination is expected to be uranium isotopes and their progeny
- Stainless steel:
 - 5,132 tons (SRS): see carbon steel for generic contamination description
 - 800 tons (INEEL): no contamination information in MIN study; wide range of contaminants expected
- Nickel:
 - 9,350 tons (PGDP): volumetrically contaminated with Tc-99

- Copper:
 - 1,400 tons (Fernald): scrap copper from Cascade Upgrade Project at PGDP
 - 220 tons (BNL): contaminated and slightly activated
- Miscellaneous:
 - 432 tons (BNL): mixed carbon and stainless steel; contaminated and slightly activated
 - 6,750 tons (Fermilab): slightly activated miscellaneous steel

Scrap metal at ORNL is primarily contaminated with fission products, such as Cs-137 and Sr-90, and activation products (DOE 1995a).

3.1.2 The Parsons (HAZWRAP) Study

In the fall of 1994, essentially contemporaneous with the MIN study, Parsons Engineering Science, Inc., conducted a study for the Hazardous Waste Remedial Actions Program (HAZWRAP) on DOE scrap metal inventory (Parsons et al. 1995). The survey included 14 DOE sites. The survey did not include concrete nor did it include any estimates of future scrap metal generation from planned D&D activities. Inventories by site are summarized in Table 3-3.

If one adds the RFETS and the Weldon Spring data from Table 3-3 to the summary quantities from the MIN study in Table 3-2, the results are very comparable. The information in Table 3-3 shows that the three gaseous diffusion plants are the source of about 50 percent of the ferrous metals stockpiles and about 90 percent of the aluminum stockpiles. Virtually all the Weldon Spring material has now been disposed of, either by release to a scrap dealer (240 tons) or burial in an onsite cell (Bishop et al. 1999). Thus, the contribution of ferrous scrap from the gaseous diffusion plants to the total is actually over 60 percent of the inventory.

The Parsons study qualitatively characterized materials as to whether or not they were contaminated but provided no quantitative estimates of the level of contamination or the mix of radionuclides contributing to the contamination. Contaminated and uncontaminated quantities are compared in Table 3-4. The totals in Table 3-3 and Table 3-4 differ slightly; these differences are due to rounding and to an inability to read some of the figures in the available copy of Parsons et al. (1995). An itemized scrap metal list from the Parsons study is included in Appendix F.

Table 3-3. DOE Scrap Metal Inventories Based on Parsons et al. (1995) (in tons)

| DOE Site | Ferrous Metals | Aluminum | Copper |
|-----------------------|---------------------|----------|--------|
| K-25 | 35,432 | 1,211 | 46 |
| Y-12 | 11,242 | 42 | 48 |
| ORNL | 1,387 | 22 | 2 |
| Paducah | 46,149 | 4,581 | 43 |
| Portsmouth | 10,774 | 345 | 23 |
| Hanford | 2,903 | -- | -- |
| INEEL | 1,522 | -- | -- |
| NTS ^a | 57 | 1 | |
| LANL | 3,383 | 24 | -- |
| RFETS | 24,300 | -- | 2,700 |
| SRS | 14,474 ^b | 15 | 12 |
| Pinellas ^c | 33 | 8 | 8 |
| FEMP | 422 | -- | 1300 |
| Weldon Spring | 30,011 | 561 | 51 |
| Total | 182,089 | 6,810 | 4,233 |

- a The NTS site was not surveyed but data from a then-current INEEL Report (Funk 1994) containing information for NTS were included in the DOE rollups in the Parsons et al. 1995 report.
- b Much of the contaminated inventory is stainless steel heat exchangers. The total in Table 3-3 includes 5,132 tons of stainless steel, of which 4,900 tons is heat exchangers.
- c This is all noncontaminated material, which is typically sold at auction.

A major difference between the Parsons study (Table 3-4) and the MIN study (Table 3-2) is that the Parsons study characterizes large amounts of material as “contaminated,” while the MIN study lists many of these same materials as “unspecified” with regard to contamination. Neither study specifically defined the basis for judging whether materials were clean (uncontaminated) or contaminated. The characterizations may have been based on DOE Order 5400.5, Radiation Protection of the Public and the Environment, which uses clearance criteria similar to NRC Regulatory Guide 1.86, but that supposition is speculative.

Additional comments on the existing stockpiles and estimates of future scrap generation from D&D activities at various DOE sites are presented in Sections 3.2 and 3.3.

Table 3-4. Comparison of Contaminated and Uncontaminated Scrap Metal Inventories Based on Parsons et al. (1995) (in tons)

| Site | Ferrous Metals | | Aluminum | | Copper | |
|---------------|----------------|-----------|----------|-----------|---------|-----------|
| | Contam. | Uncontam. | Contam. | Uncontam. | Contam. | Uncontam. |
| FEMP | 186 | 236 | | | 1,300 | |
| Hanford | | 2,902 | | | | |
| INEEL | 601 | 1,249 | | | | |
| K-25 | 33,962 | 1,472 | 1,171 | 40 | 46 | |
| LANL | 3,383 | | 24 | | | |
| NTS | 57 | | 1 | | | |
| ORNL | 242 | 1,126 | | 22 | 1 | 1 |
| Paducah | 45,224 | 924 | 4,571 | 7 | 29 | 14 |
| Pinellas | | 36 | | 8 | | 8 |
| Portsmouth | 10,691 | 83 | 338 | 7 | | 22 |
| RFETS | 24,300 | | | | 2,700 | |
| SRS | 7,190 | 7,284 | 10 | 5 | | 12 |
| Weldon Spring | 30,011 | | 561 | | 51 | |
| Y-12 | 8,658 | 2,587 | 23 | 19 | 30 | 18 |
| Totals | 164,505 | 17,899 | 6,699 | 108 | 4,157 | 75 |

3.1.3 Year 2000 Data Call

In the fall of 2000, DOE initiated a complex-wide data call to develop information on scrap metals in inventory and expected to be generated from D&D activities through the year 2035 (Neave 2001). The data call did not request specific information on activity levels. After receiving the data, DOE (EM) conducted a high-level quality assurance screening review via telephone interviews with selected sites to examine the assumptions underlying the submittals. During the QA review, DOE removed any metals requiring remote handling. In addition, the remaining quantities of steel and iron were reduced by 25 percent based on decommissioning experience at the K-25 Gaseous Diffusion Plant. Application of this factor was designed to eliminate material that could not be recycled for economic or radiological reasons. Based on this high-level quality assurance review, DOE developed ranges for the estimates from the field locations. The data (rounded to three significant figures) are summarized below:

| Material | Minimum Estimate (tons) | Data Call Estimate (tons) |
|---------------------|------------------------------------|--------------------------------------|
| Carbon Steel & Iron | 827,000 | 1,160,000 |
| Stainless Steel | 153,000 | 232,000 |
| Nickel | 31,200 | 37,700 |
| Totals | 1,010,000 | 1,430,000 |

Details of the minimum estimate are included in Table 3-5.

It can be seen from the data in this table that the GDPs at K-25 Site, Portsmouth, and Paducah account for about 57 percent of the total scrap metal. DOE ascribes a high level of confidence to these numbers. D&D of the K-25 Site is ongoing; D&D at Portsmouth is expected to run from FY 2003 to FY 2014 and for Paducah from FY 2008 to FY 2015. DOE does not have a high level of confidence in the outyear data for many sites. According to DOE, “approximately 91 percent of the available metal is contaminated. However, discussions with the sites indicate that the contamination levels would be relatively low” (Neave 2001).

A slightly modified version of the data set presented in Table 3-5 was used in a DOE study on the feasibility of setting up a dedicated melting facility to recycle DOE scrap metal for use in satisfying the Department’s requirements for radioactive waste disposal containers (Geiger 2001).

Table 3-5. Minimum Scrap Metal Estimates by DOE Facility Location (in tons)

| Site | Material | Inventory | | | | | | | | | | | | | | | | Totals |
|----------------|----------------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|-------|------|-----------|-----------|-----------|-----------|-----------|---------|
| | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011-2015 | 2016-2020 | 2021-2025 | 2026-2030 | 2031-2035 | |
| ANL-E | Carbon + Iron | 40 | 4 | 67 | 59 | - | - | - | - | - | - | - | - | - | - | - | - | 169 |
| | Stainless | - | - | 5 | 5 | - | - | - | - | - | - | - | - | - | - | - | - | 9 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| BNL | Carbon + Iron | 420 | - | 411 | 5 | 4 | - | 127 | 1,322 | 26 | - | - | - | - | - | - | - | 2,314 |
| | Stainless | - | - | - | - | - | - | 26 | 62 | 0 | - | - | - | - | - | - | - | 88 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| K-25 Site | Carbon + Iron | 31,786 | 32,532 | 28,000 | 23,889 | 22,542 | 18,206 | 34,895 | 31,851 | 21,981 | 9,598 | - | - | - | - | - | - | 255,280 |
| | Stainless | 103 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 103 |
| | Nickel + Monel | 81 | 1,826 | 1,503 | 1,174 | 927 | 529 | 692 | 885 | 613 | 272 | - | - | - | - | - | - | 8,502 |
| Fernald | Carbon + Iron | - | 7,976 | 13,902 | 10,998 | 7,998 | 902 | - | - | - | - | - | - | - | - | - | - | 41,775 |
| | Stainless | - | 977 | 4,598 | 2,709 | 180 | - | - | - | - | - | - | - | - | - | - | - | 8,463 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hanford | Carbon + Iron | - | 544 | 603 | 491 | 548 | 1,015 | 1,192 | 312 | 667 | 288 | 123 | 3,610 | 1,181 | 58 | 58 | 58 | 10,744 |
| | Stainless | - | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 58 | 58 | 58 | 58 | 58 | 403 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| INEEL | Carbon + Iron | 413 | 546 | 489 | 245 | 546 | 3,677 | 489 | 489 | 286 | 489 | 546 | 19,615 | 31,875 | 24,528 | 12,281 | 17,194 | 113,710 |
| | Stainless | 1,313 | 546 | 489 | 245 | 546 | 3,677 | 489 | 489 | 286 | 489 | 546 | 19,615 | 31,875 | 24,528 | 12,281 | 17,194 | 114,610 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| LBL | Carbon + Iron | - | - | - | 6,800 | 2,465 | - | - | - | - | - | - | - | - | - | - | - | 9,265 |
| | Stainless | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| LLNL | Carbon + Iron | - | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 250 | 250 | 250 | 250 | 250 | 1,750 |
| | Stainless | - | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 250 | 250 | 250 | 250 | 250 | 1,750 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Naval Reactors | Carbon + Iron | - | 83 | 108 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 413 | 413 | 413 | 413 | 413 | 2,913 |
| | Stainless | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| NTS | Carbon + Iron | - | - | 677 | - | 148 | - | 1,115 | - | 22 | - | - | 392 | - | - | - | - | 2,354 |
| | Stainless | 78 | | | | | | | | | | | | | | | | 78 |
| | Nickel | | | | | | | | | | | | | | | | | - |

Table 3-5. Minimum Scrap Metal Estimates by DOE Facility Location (in tons) (continued)

| Site | Material | Inventory | | | | | | | | | | | | | | | | Totals |
|-------------------|----------------|-----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|-----------|-----------|-----------|-----------|-----------|---------|
| | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011-2015 | 2016-2020 | 2021-2025 | 2026-2030 | 2031-2035 | |
| ORNL | Carbon - Iron | - | 131 | 442 | 271 | 217 | 1,296 | 1,500 | 1,099 | 498 | 85 | 94 | 170 | - | - | - | - | 5,803 |
| | Stainless | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Paducah | Carbon - Iron | 29,494 | 394 | 1,182 | 1,455 | 1,455 | 364 | 2,190 | 1,574 | 22,078 | 21,826 | 21,826 | 43,652 | - | - | - | - | 147,489 |
| | Stainless | 31 | 394 | 1,182 | 1,455 | 1,455 | 364 | - | - | - | - | - | - | - | - | - | - | 4,880 |
| | Nickel | 8,735 | - | - | - | - | - | - | - | 1,174 | 1,174 | 1,174 | 2,346 | - | - | - | - | 14,602 |
| Portsmouth | Carbon + Iron | 9,696 | - | - | 27,496 | 27,496 | 27,496 | 27,496 | 27,496 | - | - | - | - | - | - | - | - | 147,176 |
| | Stainless | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 |
| | Nickel + Monel | 15 | - | - | 1,607 | 1,607 | 1,607 | 1,607 | 1,606 | - | - | - | - | - | - | - | - | 8,050 |
| PPPL | Carbon + Iron | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Stainless | 79 | 416 | 416 | - | - | - | - | - | - | - | - | - | - | - | - | - | 911 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| RFETS | Carbon + Iron | - | 1,218 | 2,544 | 3,297 | 11,440 | 14,979 | 6,646 | - | - | - | - | - | - | - | - | - | 40,124 |
| | Stainless | - | 517 | 1,092 | 1,111 | 1,595 | 1,347 | 35 | - | - | - | - | - | - | - | - | - | 5,697 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| SRS | Carbon + Iron | 3,268 | 635 | 635 | 573 | 573 | 503 | 503 | 623 | 623 | 1,166 | 1,199 | 4,310 | 1,353 | 1,890 | 2,049 | 1,718 | 21,619 |
| | Stainless | 4,816 | 468 | 468 | 463 | 463 | 435 | 435 | 465 | 465 | 601 | 609 | 1,851 | 1,112 | 1,246 | 1,286 | 1,203 | 16,386 |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Y-12 | Carbon + Iron | 20,408 | - | - | - | - | - | 137 | 2,853 | 160 | 149 | 982 | 3,143 | 33 | - | - | - | 27,845 |
| | Stainless | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Nickel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Annual Totals | Carbon + Iron | 95,523 | 44,029 | 49,000 | 75,628 | 75,482 | 68,488 | 76,340 | 67,651 | 46,389 | 33,650 | 24,820 | 75,142 | 34,692 | 26,726 | 14,638 | 19,220 | 827,418 |
| | Stainless | 6,420 | 3,379 | 8,311 | 6,048 | 4,301 | 5,884 | 1,047 | 1,077 | 813 | 1,152 | 1,217 | 21,773 | 33,294 | 26,082 | 13,875 | 18,705 | 153,378 |
| | Nickel | 8,831 | 1,826 | 1,503 | 2,781 | 2,534 | 2,136 | 2,299 | 2,491 | 1,786 | 1,446 | 1,174 | 2,346 | - | - | - | - | 31,154 |
| Cumulative Totals | Carbon + Iron | 95,523 | 139,553 | 188,553 | 264,180 | 339,663 | 408,151 | 484,490 | 552,142 | 598,531 | 632,181 | 657,001 | 732,143 | 766,834 | 793,560 | 808,198 | 827,418 | |
| | Stainless | 6,420 | 9,799 | 18,110 | 24,158 | 28,459 | 34,343 | 35,391 | 36,468 | 37,281 | 38,432 | 39,649 | 61,422 | 94,716 | 120,798 | 134,673 | 153,378 | |
| | Nickel | 8,831 | 10,657 | 12,161 | 14,941 | 17,476 | 19,612 | 21,911 | 24,402 | 26,189 | 27,634 | 28,808 | 31,154 | 31,154 | 31,154 | 31,154 | 31,154 | |

3.2 Gaseous Diffusion Plants

The DOE has operated three gaseous diffusion plants, including the K-25 Site¹⁰ at Oak Ridge, Tennessee, the Paducah Gaseous Diffusion Plant in Kentucky, and the Portsmouth Gaseous Diffusion Plant in Ohio, to produce enriched uranium for the nuclear weapons program and for fuel in commercial power reactors. Portions of the K-25 Site were shut down as early as 1964, and all operations were terminated in 1987 (NAS 1996). Decontamination and decommissioning (D&D) programs are being actively pursued at the K-25 Site. The Portsmouth and Paducah facilities are currently under lease to the U.S. Enrichment Corporation, and D&D will not be initiated until the leases are terminated. On March 3, 1997, these two plants came under NRC regulation (NRC 1998). Highly enriched uranium (>90 percent U-235) was produced both at the K-25 Site and at Portsmouth. The maximum enrichment at PGDP was 2.75 percent (NAS 1996). Recently, it was announced that U.S. Enrichment plans to suspend operations at the Portsmouth plant in June 2001. DOE would spend \$630 million over the next five years to keep the plant in a cold standby basis permitting rapid reopening (Post 2000).

The scrap tonnages from the GDPs discussed in this section are based on earlier studies than those presented in Table 3-5. However, the tonnages are similar in magnitude.

3.2.1 Quantities of Scrap Materials from D&D

In October 1991, Ebasco (now Foster Wheeler Environmental Corporation) issued a report entitled *Environmental Restoration of the Gaseous Diffusion Plants* that provided cost estimates for D&D (Ebasco 1991). Quantities of scrap metal expected to result from these operations were derived from the Ebasco report and summarized in DOE 1993. The results are presented in Table 3-6, which excludes “a significant amount of structural steel left in place” in decontaminated building structures.

The estimates in Table 3-6 do not include any scrap metal in storage yards at the three sites; only materials expected from D&D are included. The total scrap metal included in this table is 708,000 tons.

¹⁰ DOE has renamed the K-25 Site as the East Tennessee Technology Park in recognition of DOE's objective of site reuse by private sector firms.

**Table 3-6. Radioactive Scrap Metal Streams Arising from
Decommissioning Gaseous Diffusion Plants (000 tons)**

| Category | K-25 Site | Paducah | Portsmouth | Metal Totals |
|--|------------------|----------------|-------------------|---------------------|
| Ferrous metals/steel | 103.7 | 74.0 | 91.4 | 269.1 |
| Aluminum/copper | 8.5 | 6.1 | 7.6 | 22.2 |
| Copper wire, tubing, valves | 17.6 | 11.7 | 15.0 | 44.3 |
| Monel pipe/valves | 1.7 | 1.2 | 1.5 | 4.4 |
| Nickel | 22.1 | 15.9 | 19.8 | 57.8 |
| Misc. electrical/instrumentation equipment and housings | 123.2 | 81.9 | 105 | 310.1 |
| Site Totals | 276.8 | 190.8 | 240.3 | 707.9 |

Source: DOE 1993

Additional details on the scrap expected at the K-25 Site are included in Table 3-7 (DOE 1993). The totals in this table are slightly greater than those in Table 3-6 because the following were excluded from Table 3-6:

- HVAC equipment: 16.2 tons
- Non-process equipment: 6.9 tons
- Miscellaneous parts: 5.6 tons

“Clean” or “contaminated” are the expected end states of the material after decontamination according to concepts developed by Ebasco.

In a 1994 presentation to the National Academy of Sciences Committee on Decontamination and Decommissioning of Uranium Enrichment Facilities, Faulkner (1994) provided an estimate of quantities of materials to be generated during D&D of the K-25 Site. His estimate was the same as that presented in Table 3-6, except that miscellaneous materials were not included and copper was estimated to be 9,700 tons rather than 17,600 tons. Reasons for these differences are not apparent.

Table 3-7. Materials Generated from the K-25 Site D&D Program (000 tons)

| Material | 000 tons |
|---|----------|
| <i>Ferrous Metals/Steel</i> | |
| Outside utilities & tie lines, misc. steel | 1.4 |
| D&D building, misc. steel | 13.5 |
| Crane dismantling, equipment | 1.1 |
| Carbon steel and stain. steel pipe and valves | 5.3 |
| Small process equipment | 1.9 |
| Clean carbon steel | 29.3 |
| Contaminated carbon steel | 7.3 |
| Clean large pipe | 18.2 |
| Contaminated large pipe | 2.0 |
| Large valves | 9.3 |
| Steel enclosures/housings | 16.3 |
| HVAC equipment, ducting, vents, air intakes | 16.2 |
| Nonprocess equipment | 6.9 |
| <i>Copper, Aluminum and Nickel</i> | |
| Copper tubing/valves | 0.21 |
| Large copper wire | 9.5 |
| Small copper wire | 7.9 |
| Aluminum/copper from converters | 8.5 |
| Monel pipe/valves | 1.73 |
| Barrier tube and other nickel | 22.1 |
| Misc. parts (compressor seals, etc.) | 5.6 |
| <i>Miscellaneous</i> | |
| Electrical switchgear (outside utilities) | 1.8 |
| Transformer, circuit breaker, condenser | 23.5 |
| Nonprocess piping | 0.36 |
| Fire protection | 15.0 |
| Instrument air | 0.79 |
| Transformers (inside electrical/instruments) | 18.8 |
| Capacitors | 0.9 |
| Motors | 17.4 |
| Conduit and cable trays | 24.0 |
| Switchgear, instrument/control panel housings | 20.7 |
| Grand Total | 307.49 |

Under the Energy Policy Act of 1992, a fund was established to pay for the cleanup costs at the diffusion plants. Pursuant to the Act, DOE is required to provide a report to Congress every three years that includes an assessment of the adequacy of the funds to pay for the D&D. DOE requested that Lockheed Martin Energy Systems, Inc. (LMES) prepare an updated cost estimate in October 1995, to capture the savings associated with recycling more effectively than had been done in previous estimates. The results of the one-month study are described in Person et al., 1995. Some of the key assumptions in the 1995 LMES study are:

- Facilities removed to grade level
- Equipment spot-decontaminated only as necessary for personnel health and safety needs, then recycled into containers for DOE use
- Structural steel spot-decontaminated as needed, surveyed, and released for unrestricted use
- Concrete walls and floors washed to remove loose contamination then demolished and left in covered rubble pile

In the LMES study, it was envisioned that the metals in contaminated equipment would be picked up at the site by a contractor and transported to his facility where the materials would be segregated, sized, melted, rolled into flat products, and fabricated into containers for DOE use. Recycle would be at a rate of about 45,000 tons per year through one NRC-licensed recycler at each diffusion plant site. The recycler would handle both equipment for internal recycle and structural steel for unrestricted use after any necessary decontamination. The only equipment with reuse potential is electric motors, with 80 percent assumed to be free-released (cleared) and the balance recycled. Based on these assumptions, LMES prepared the estimates presented in Table 3-8 for metals and other materials. One of the authors of the LMES study subsequently provided estimates of the relative amounts of recycled metal in Table 3-8, which would be available for unrestricted release and for internal recycle and reuse (Person 1996). The criteria for unrestricted release were not specified. The rubble pile data in Table 3-8 as reported in Person et al. 1995 were converted to concrete tonnage estimates for the present study by assuming that 95 percent of the rubble pile was concrete and that the crushed concrete had a density of 100 lb/ft³ based on a discussion with G. Person on August 25, 1999 (Person 1999).

Table 3-8. Major Material Streams from D&D of Gaseous Diffusion Plants
Requiring Recycle or Disposal

| Facility | Total Metal (tons) | Metal Recycled (tons) | Metal Free- Released ^a (tons) | Metal Recycled within DOE ^a (tons) | Building Rubble Pile (000 ft ³) | Concrete (tons) |
|------------|-----------------------|-----------------------------|--|---|---|--------------------|
| K-25 | 460,811 | 447,054 | 213,000 | 234,000 | 14,548 | 691,000 |
| Paducah | 371,056 | 364,538 | 111,000 | 254,000 | 8,622 | 410,000 |
| Portsmouth | 350,910 | 343,238 | 135,000 | 208,000 | 9,507 | 452,000 |
| Total | 1,182,777 | 1,154,830 | 458,000 | 696,000 | 32,677 | 1,553,000 |

a Rounded to three significant figures

The quantities of metals in Table 3-8 are substantially greater than those in Table 3-6. This is probably because the 1995 LMES study assumed that buildings would be razed and structural steel recovered for sale, while the 1993 DOE study assumed (as did the prior Ebasco study) that significant quantities of structural steel would be left in place. In Table 3-6, the total quantity of metal is 708,000 tons, while in Table 3-8, the total quantity of metal for internal recycle within the DOE complex is 696,000 tons, which supports the suggested reconciliation of the estimates. The D&D timetable developed by Person et al. (1995) assumed that activities at the K-25 Site would be conducted over a nine-year period (1998 through 2006), activities at Portsmouth would be conducted from 2007 through 2015, and activities at PGDP would be conducted from 2015 to 2023. While actual work at the K-25 Site is generally consistent with this schedule, comprehensive D&D and cleanup of the other two sites cannot begin until the U.S. Enrichment Corporation terminates its leases.

3.2.2 Radioactivity Levels

Radioactivity in the gaseous diffusion plants consists of U-234, U-235, and U-238, which naturally occur in uranium ores,¹¹ their short-lived progeny, and Tc-99, U-236, and trace quantities of Np-237 and Pu-239. This contamination was introduced into the plants with reprocessed uranium fuel from plutonium production reactors at Hanford and Savannah River (NAS 1996). Eighty-eight percent of the reprocessed uranium was shipped to PGDP and 12 percent to the K-25 Site. Of the contamination in the reprocessed uranium feed shipped to Paducah, only about 85 percent of the Tc-99 and about 25 percent of the Np-237 and Pu-239

¹¹ Natural uranium contains 0.712 percent U-235, 99.282 percent U-238, and trace amounts of U-234 (0.006%).

actually entered the cascade because of losses sustained when the uranium (as UO_3) is converted to UF_6 , and when the UF_6 is vaporized prior to being fed into the cascade (Smith 1984). Similarly, at K-25, only 25 percent of the Np-237 and 1.5 percent of the Pu-239 entered the cascade. Smith (1984) estimated that 539 kg of Tc-99, 4.6 kg of Np-237, and 0.1 g of Pu-239 were fed into the Paducah cascades from 1953 until September 11, 1975, when use of reactor return feeds was discontinued. Much of the contamination that had been deposited prior to 1975, when this feed source was eliminated, was removed during the cascade improvement and upgrade programs in the 1980s (NAS 1996). Some of this contamination is also present at the Portsmouth plant.

Table 3-9 provides information on the estimated fraction of the surface area that is contaminated (at levels exceeding Regulatory Guide 1.86) in various buildings at the K-25 Site (NAS 1996). The five process buildings constitute about 90 percent of the total area under roof at the K-25 Site. The high-enrichment buildings, K-25 and K-27, were shut down in 1964. Low-enriched uranium continued to be produced in the other process buildings until 1985 (NAS 1996).

Table 3-9. Estimated Percentages of Surface Areas at the K-25 Site Contaminated with Radioactive Materials

| Site Facilities | U-235 Enrichment | Building Floor Space | Building Walls | Structural Steel | Nonprocess Equipment | Process Equipment Housings | Process Electrical Systems | Uranium Processing Equipment |
|---------------------------------|------------------|----------------------|----------------|------------------|----------------------|----------------------------|----------------------------|------------------------------|
| K-25 process building (94%) | 20-90 | 15 | 10 | 10 | Unknown | 90 | — ^a | 100 |
| 311-1 Area (6%) | 3-5 | 95 | 90 | 90 | | 100 | | 100 |
| K-27 process building (80%) | Up to 20 | 15 | 15 | 15 | Unknown | 90 | — ^a | 100 |
| 402-9 Area (20%) | 3-5 | 90 | 80 | 80 | | 100 | | 100 |
| K-29 process building | 2-10 | 90 | 80 | 85 | Unknown | NA | — ^a | 100 |
| K-31 process building | 1-4 | 15 | 10 | 10 | Unknown | 50 | — ^a | 100 |
| K-33 process building | 0.2-2 | 5 | 5 | 5 | Unknown | 50 | — ^a | 100 |
| Process support buildings | 0.2-5 | 15 | 10 | 10 | Unknown | 70 | — ^a | 100 |
| Decontamination buildings | 0.2-5 | 90 | 90 | 90 | Unknown | 100 | — ^a | 100 |
| Water and electrical facilities | NA ^b | ^c | ^c | ^c | Unknown | NA | NA | NA |

NOTE: This assessment is based on limited data collected during facility operation; detailed characterization has been delayed until D&D activities are initiated in the buildings. Surfaces are considered contaminated if 5,000 disintegrations per minute (dpm) or more can be detected. Surface contamination can be found from 5,000 dpm/100 cm² to greater than one million dpm/100 cm². Most of the contamination is either uranium or Tc-99. Areas 311-1 and 402-9 are the purge cascades for the K-25 and K-27 buildings respectively. Area 311-1 operated until 1977, and 402-9 operated until 1985.

- a Due to the difficulties in surveying motor and transformer windings, these components have been treated as contaminated in previous maintenance programs.
b NA=Not available.
c Spot contamination may be found.

Source: Faulkner 1994. Reprinted from NAS 1996.

3.2.3 Recent Decontamination and Decommissioning Activities

3.2.3.1 Small Scale Metals Recycle Project

In 1995 and 1996, DOE conducted the Small Scale Metals Recycle Project at the K-25 Site. The purpose of the project was to demonstrate that it was technically and economically feasible to reuse or recycle equipment and materials from D&D of the gaseous diffusion facilities. During the project, six large electric motors were shipped to AERC (a State of Tennessee materials licensee) for decontamination (Lockheed Martin 1996). Using a variety of decontamination processes, including surface wipe down, high-pressure, low-volume water and chemical spray down, CO₂ and abrasive grit blasting and mechanical removal, the motors were decontaminated to meet the limitations for unrestricted use. A limited survey identified no reuse market, but three commercial firms provided quotes of 6 to 7 cents per pound for the contained steel and copper as scrap metal.

One diffusion plant cell (Unit 2, Cell 9) and a portion of a second (Unit 2, Cell 7) in Building K-31 were dismantled during the project. A total of 10 compressors, 10 convertors, and 10 motors were removed. An additional 74 tons of metal was removed from Cell 7. In all, the project identified a total of 636 tons of scrap metal. (Some of this metal came from Building K-33, Vault 32A, and the K-1064 storage yard in addition to Building K-31.) A total of 536 tons of ferrous metals was shipped to Manufacturing Sciences Corp. (MSC) for beneficial reuse (melting and fabrication into waste storage containers) within DOE. The remaining 100 tons were not recycled because of issues such as the presence of lead, excess rust, asbestos, and PCBs, as well as complicated construction involving incompatible materials, such as copper and cast iron.

Significant information on radioactivity levels at the K-25 Site is included in the Lockheed Martin (1996) report. Average enrichment levels for various buildings used in the enrichment process at the K-25 Site are presented in Table 3-10.

Contamination measurements taken during the project are summarized in Table 3-11 (Lockheed Martin 1996). These volumetric contamination measurements were converted from surface activity measurements using actual geometries of the components (Howell 1999).

Table 3-10. Average Enrichments at Various K-25 Site Buildings

| Building | Enrichment (% U-235) |
|----------|----------------------|
| K-25 | >20-95 |
| K-27 | 12 |
| K-29 | 3 |
| K-31 | 1.2 |
| K-33 | 0.74 |
| K-631 | <0.711 |
| K-633 | <0.711 |

Table 3-11. Radionuclide Concentrations from Small Scale Metals Recycle Project

| Source | Uranium Activity Concentration (pCi/g) | Transuranic Activity Concentration (pCi/g) | Technetium Activity Concentration (pCi/g) |
|-------------------------|--|--|---|
| Building K-31 | 84 | 0.4 | 157 |
| Building K-31, Cell 9 | 123 | 1.7 | 91 |
| Building K-33 | 54 | 0.1 | 67 |
| Vault 32A | 34 | 0.6 | 243 |
| K-1064 Storage Yard | 5.5 | 0.3 | 37 |
| Average - all shipments | 51 | 0.5 | 125 |
| Maximum - all shipments | 4,451 | 8.6 | 2,062 |

The report also noted that the relative activities for TRU radionuclides were 50 percent Np-237, 20 percent Am-241, 20 percent Pu-239, and 10 percent Pu-238.

The distribution of surface activity for the project has recently been reported (Kerr et al. 1999). This distribution is reproduced here as Figure 3-1. Approximately 2000 samples with fixed beta/gamma activities ranging from less than 1,000 to more than 10 million dpm/100 cm² were recorded.

Sampling Statistics - Building K-31

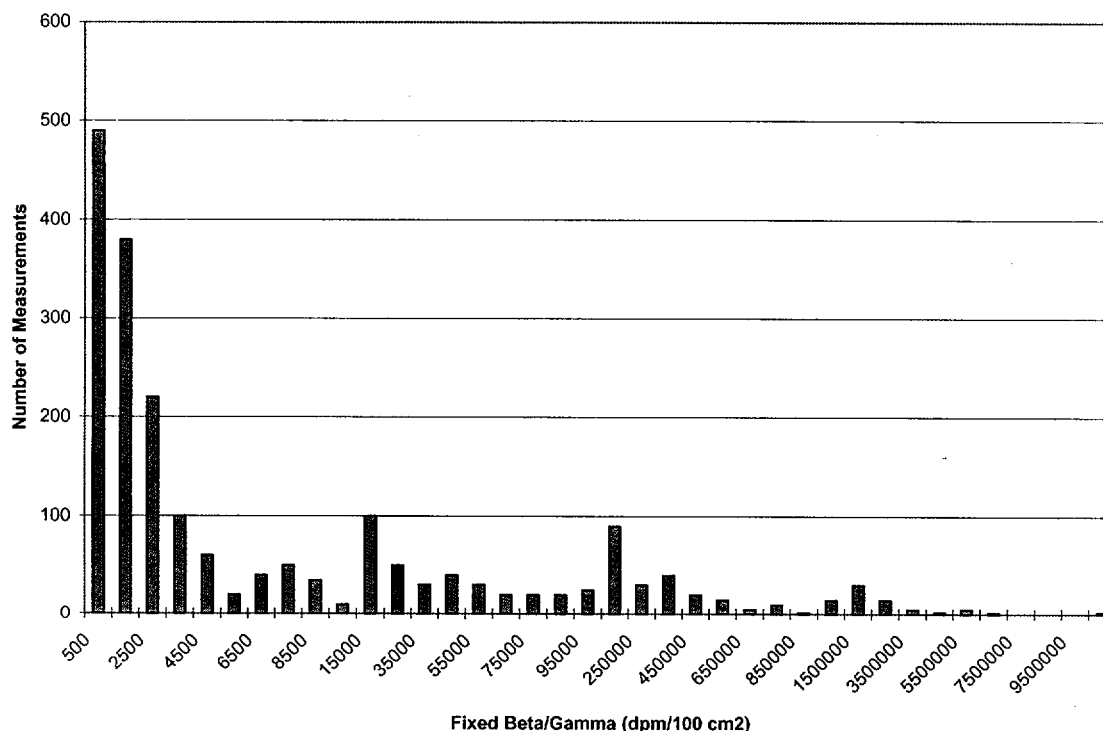


Figure 3-1. Histogram of Fixed Beta/Gamma Measurements from Small Scale Metals Recycle Project (Kerr et al. 1999)

3.2.3.2 BNFL Three-Building D&D

DOE has recently awarded several contracts related to D&D and recycle at the K-25 Site. In August 1997, BNFL Inc. was awarded a \$238 million fixed-price contract to deliver three vacant and decontaminated buildings (K-29, K-31, and K-33) to DOE. Under the contract, BNFL will design, license, and construct necessary decontamination facilities, operate the facilities to decontaminate metals and equipment, salvage metals and equipment, and deactivate the decontamination facilities (Bishop et al. 1999). The anticipated quantity of recyclable material from the three buildings is 117,162 t, including 12,138 t from K-29, 34,792 t from K-31, and 70,232 MT from K-33. These buildings comprise 40 percent of the square footage at the K-25 Site (http://207.153.212.107/projects_ettp.html). The contract is scheduled to run through the end of 2003. As of January 1, 1999, 10 percent of the 2.8 million square foot K-33 building had

been cleaned up: 590 MT of material had been surveyed, 370 MT had been shipped offsite for reuse, and 54 MT had been decontaminated for recycling (http://207.153.212.107/projects_ettp.html). Some of this material was clean and was released directly; some was transferred to another contractor (MSC) for decontamination before release (Gresalfi 1999). BNFL is adding a metal size-reduction facility at K-33, which will process about 63 MT of metal per day. (This is equivalent to about 1.3 diffusion plant stages consisting of a motor, compressor, and convertor.) The DOE approach to these three of the five major process buildings is to clean up and decommission them prior to leasing the facilities for private sector use. This means that large quantities of structural steel will not be released for recycle. (The K-25 building will be demolished (DOE 1999).) Thus, the clearable (free-released) quantities of materials quoted for the K-25 Site in Table 3-8 will not be realized.

DOE has also funded Option I under the BNFL contract, which involves removal of equipment from the electrical switchyards for buildings K-31 and K-33 (Bishop et al. 1999). The switchyards, designated K-762 and K-792, respectively, include several buildings and structures (K-761, K-791, K-791S, and K-791N) containing nonradioactive equipment and materials. Dismantling work began in July 1998 and was essentially completed in mid-1999. As of December 1998, 10,575 metric tons of clean scrap metal had been recycled. Buildings K-791, K-791S, and K-791N were demolished to the top of their concrete slabs. Building K-761 was left intact for future reindustrialization use (<http://www.oro.doe.gov/AstYtl/metals/success.htm> - 9/22/99).

3.2.3.3 Building K-1401 D&D

Under another contract funded by DOE, ATI decontaminated a specific section of building K-1401 (Bishop et al. 1999). The area to be decontaminated contained hundreds of idle machine tools. Although the area had not been used for major uranium processing operations, fugitive emissions of vapor, fumes, and liquids had resulted in some contamination of the facility and equipment with uranium and other radioactive substances. Some of the equipment (tooling, jigs, and fixtures) was transferred to other DOE facilities. ATI sold the balance of the equipment, after demonstration that it could meet free-release standards, at public auction. A total of 900 lots of equipment (including large machine tools, such as lathes and surface grinders) and materials was sold to wholesalers and end users.

3.2.3.4 Other Gaseous Diffusion Plant Recycle Activities

Group I Buildings Demolition Project. During 1999, dismantling of five so-called Group I Building Demolition Project auxiliary buildings at the K-25 Site was completed. The buildings included K-724, K-725, K-1031, K-1131, and K-1410 (Person 1999). This operation produced about 600 tons of steel, which was free released to a scrap dealer (Bechtel Jacobs 1999). In addition, about 300 tons of scrap metal from Buildings K-1031, K-1131, and K-1410 were transferred to the ETTP LLW Scrap Yard. Attempts were made to use steel shot blasting to remove radiological contamination, but this activity was terminated when the subcontractor doing the work judged the decontamination operation to be uneconomical. Additionally, some paint on the scrap metal was found to have PCB contamination.

Following demolition, concrete, brick, and masonry from buildings K-724 and K-725 were crushed and used as earthen backfill for a low area on the K-25 Site. Maximum concentrations of uranium isotopes measured for the earthen backfill were:

- U-234: 2.63 pCi/g
- U-235: 0.122 pCi/g
- U-238: 2.38 pCi/g

Earthen material generated from demolition rubble from buildings K-1131 and K-1410 was also used for onsite fill. The maximum concentrations of various radionuclides in this earthen fill are summarized in Table 3-12. The Group I Project was reported to be continuing, and work around several buildings near K-1401 and the basement of K-1401 was scheduled for 2000.

Table 3-12. Maximum Measured Radionuclide Concentrations in Earthen Fill from Buildings K-1131 and K-1410

| Radionuclide | K-1131 Max. Concentration (pCi/g) | K-1410 Max. Concentration (pCi/g) | Volume Weighted Concentration (pCi/g) |
|--------------|--------------------------------------|--------------------------------------|--|
| Tc-99 | bg | bg | bg |
| Th-228 | bg | bg | bg |
| Th-230 | bg | 2.49 | 0.732 |
| Th-232 + D | bg | bg | bg |
| U-234 | 10.87 | 5.43 | 9.27 |
| U-235 + D | 0.68 | 0.71 | 0.69 |
| U-238 + D | 10.87 | 6.11 | 9.47 |
| Np-237 + D | 0.79 | 0.40 | 0.68 |
| Pu-238 | 0.25 | 0.90 | 0.44 |
| Pu-239 | 0.24 | 0.22 | 0.23 |

bg = maximum sample result did not exceed background concentration.

Powerhouse Area Demolition Project. Demolition of 15 structures located at the K-25 Site powerhouse was completed in 1996 (Lockheed Martin 1996a). A local broker (Knox Metals Corporation) purchased 6,477 tons of scrap metal for recycle. The composition of this scrap metal was:

- Steel: 5,450 tons
- Copper: 166 tons
- Stainless steel: 48 tons
- Miscellaneous (e.g., iron and aluminum): 813 tons

The steel was primarily structural steel and some equipment items, such as pumps, piping, switchgear, and conduit. The copper was mainly wiring. Earthen rubble from building demolition was used as backfill in the basements of the demolished buildings. The rubble was required to be crushed to less than 12, inches and any exposed rebar was cut off within 1 inch of the concrete blocks. Any incidental metals generated during demolition and crushing were removed from the fill material.

Paducah Gaseous Diffusion Plant Scrap. In FY 2000, DOE planned to remove and dispose of 9,700 tons of scrap metal from PGDP (DOE 1999). No details are available, but it is expected that, because of the moratorium, no action was taken.

3.2.3.5 Y-12 Scrap Yard

DOE has recently assessed the uranium surface contamination on Y-12 scrap yard metals (Kerr et al. 1999). As noted in Table 3-3, this scrap yard contains about 11,300 tons of material with greater than 90 percent being carbon steel. The physical forms include tables, cabinets, piping, valves, tooling, duct work, and other items. The sampling plan initially involved the use of alpha and beta detectors to identify the most highly contaminated materials samples within specific grid in the scrap yard. (This sampling procedure creates bias toward the high side and is therefore conservative.) Samples were then machined from the materials with the highest detected contamination, dissolved, and analyzed by thermal ionization mass spectrometry. A total of 71 samples were analyzed for uranium, with results ranging from 0.3 μg of U per gram of sample to 864,000 μg of U per gram of sample. The relative activity ratios for U-238, U-235, and U-234 were estimated to be 1.0, 0.038, and 0.79, respectively. These measured values (μg U per g of sample) were then converted to units of dpm/100 cm^2 using the assumption that

1,000 dpm/100 cm² equals 850 µg total U per gram of sample. These measurements are summarized in the histogram included as Figure 3-2.

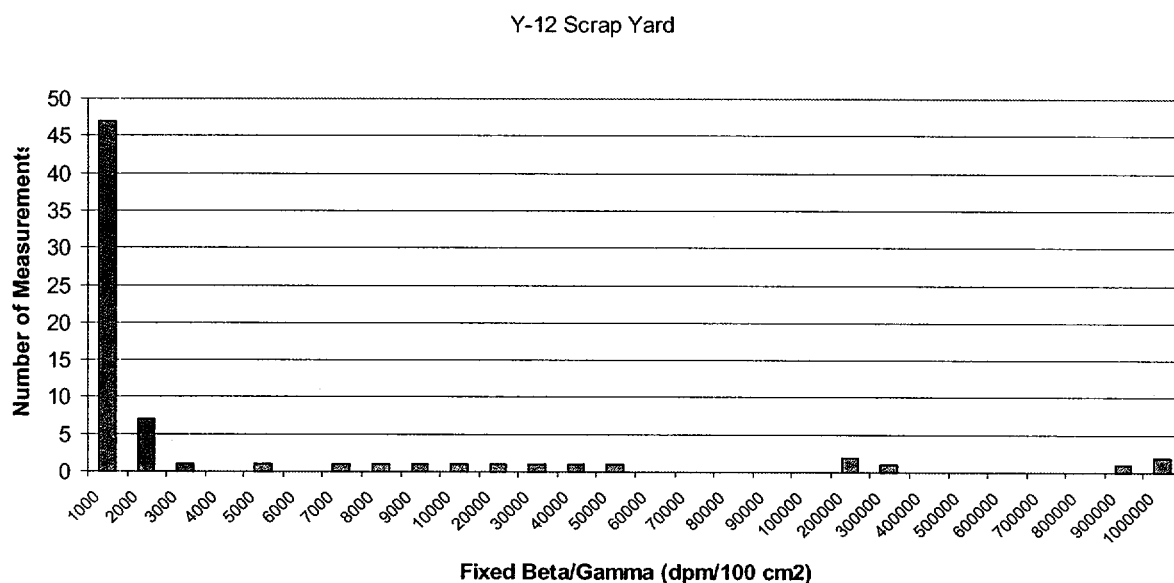


Figure 3-2. Fixed Beta-Gamma Counts for Uranium Contamination of Y-12 Scrap Yard Materials

About 80 percent of the samples had values of less than 5,000 dpm/100 cm², which is the release limit for Regulatory Guide 1.86 and DOE Order 5400.5. However, DOE estimated that decontamination and survey problems with complex shapes would limit the amount of material available for clearance to about 70 percent. The balance of the stockpile is destined for beneficial reuse as shield blocks.

3.2.3.6 Oak Ridge National Laboratory (ORNL)

ToxCo Inc. is currently processing about 220 containers of scrap metal in 40 ft³ roll-off boxes that were purchased from ORNL (Eaker 1999, Bishop et al. 1999). Apparently, the scrap was generated since the Parsons Report was prepared. The lot, which includes about 1,387 tons of ferrous metals, 22 tons of aluminum, and 2 tons of copper, is being evaluated at a leased facility at K-25. ToxCo has a State of California nuclear materials license and has applied to the State of Tennessee for a local license. Meanwhile, ToxCo is allowed to ship the scrap to the K-25 Site under a reciprocity arrangement between Tennessee and California. ToxCo currently plans to

survey and release clean material but not to do decontamination. In the future, ToxCo will be in a position to accept scrap from any source.

Bishop et al. (1999) have described other successful recycling operations at ORNL including cleanup of the Tower Shielding Facility, which produced 190.5 MT of clean scrap metal that was recycled by Southern Foundry and 277 MT of clean concrete that was reused by I-75 Crushed Stone.

3.3 Other DOE Facilities

3.3.1 Fernald Environmental Management Project (FEMP)

As noted in Table 3-4, FEMP had a considerable amount of copper in inventory, primarily in the form of copper wire and motor windings. About 1,340 tons of this material are being shipped to Oak Ridge for decontamination by Decon and Recovery Services of Oak Ridge LLC. It is expected that about 1,200 tons will be cleared for recycle and the balance disposed of as waste (Bishop et al. 1999).

FEMP evaluated several options for disposal or recycle of 15,200 tons of structural steel from the D&D of Plant 4 (100 percent of OAU 3 structural steel) (Yuracko et al. 1997). Based on a life cycle cost analysis, the steel is being buried in the On-Site Disposal Cell rather than decontaminated for recycle (Gresalfi 1999a). The steel comprises 0.09 percent of the disposal cell volume.

On the basis of these actions, Fernald is not expected to be a significant source of potentially clearable scrap metal.

3.3.2 Rocky Flats Environmental Technology Site (RFETS)

In its "Paths to Closure" report, DOE set a goal for closure of this site by 2006 (DOE 1998b). DOE does not address potentially clearable materials in that report, but rather focuses on waste volumes for disposal. DOE notes that 295,000 m³ of material will be generated from facility deactivation and decommissioning in addition to 198,000 m³ of soils. After segregation and treatment, 260,000 m³ will be placed on site and 130,000 m³ of uncontaminated/hazardous material will be disposed of at a commercial facility off site. More recently, RFETS has

estimated that 140,000 m³ of potentially clearable concrete will be generated from D&D activities (Mathis 1999). Buildings will be cleared to DOE Order 5400.5 requirements and then demolished. The concrete will then be stockpiled and eventually used as fill. Alternatively, the cleared concrete could be shipped off site for disposal in a sanitary landfill.

Dorr et al. (1997) note that there are 450 buildings at RFETS that will require decommissioning, but only 35 of these have significant levels of radiological and chemical contamination. These authors describe the D&D of Building 889, an 8,000 ft² structure erected on a reinforced concrete slab. Excess equipment, chemicals, tools, and furniture were first removed, recycled, and/or salvaged. Building utilities, including process waste piping, an overhead crane, ventilation ducting, a drum compactor, and bailer, were then removed. The floors and walls of the building were contaminated to levels as high as 120,000 dpm/100 cm². This contamination was removed by scabbling. The decontaminated building was then demolished with a backhoe equipped with an hydraulic shear. Piping penetrations in the slab were sealed, and the slab was left in place. The foundation, underlying soil, and capped sumps will continue to be controlled. Decommissioning debris included 135 m³ of low-level waste, 324 m³ of sanitary waste, and 135,000 kg of scrap metal.

3.3.3 Hanford Site

The Federal Government is expected to remain as landlord of the Hanford Site after cleanup is completed. Large facilities exist at Hanford, including the plutonium production reactors and fuel processing chemical plants (canyons), which will generate significant quantities of waste when decommissioned. Nine retired plutonium production reactors are located in the 100 Area at Hanford. Seven have been placed in safe storage, the C-Reactor is in interim safe storage, and the B-Reactor structure is expected to remain as a National Historic Landmark (DOE 1998b). Although it is not known to what extent these facilities contain materials or equipment sufficiently low in radioactivity to be cleared for recycle or reuse, some projections are made in the ensuing paragraphs. Soils, rubble, and debris are expected to be disposed of in the onsite Environmental Restoration Disposal Facility (ERDF) (DOE 1998b, p. 3-28).

The method chosen to place the C-Reactor in interim safe storage was to “cocoon” the reactor core with three- to five-foot walls and a high-strength, corrosion-resistant gavalum roof with a 75-year lifetime (i.e., the duration of the safe storage period) (Crigler 1999). During the cocooning process, 23 buildings at the reactor site were removed and the footprint of the reactor

building was reduced by 80 percent. Approximately 15,600 tons of LLW, including 12,000 tons of concrete, 70 tons of lead, 1,000 tons of steel, and 1,700 tons of soil, were sent to Hanford's ERDF. An additional 400 tons of steel, 2.5 tons of copper, 40 tons of lead, and one gallon of mercury were recycled.

Hanford is evaluating disposal options for the steam system piping from the 105N Reactor steam generator to the Hanford Generating Plant, which was shut down in 1989 (Griffin and Plagge 1997). The carbon steel piping consists of eight 38-inch i.d. (inner diameter) pipes having a total length of 9,165 feet, two 24-inch i.d. pipes with a total length of 1,950 ft, and two 12-inch i.d. pipes also with a total length of 1,950 ft. The weight of the piping is 1,563 tons. Weight of the trestle structure supporting the piping was not estimated. The pipes "potentially contain minimal radiological contamination," while the trestle structure is assumed to be uncontaminated. If surveys of the disassembled piping show acceptable levels of contamination, the sectioned pipes will be sold to a scrap dealer. Otherwise, the pipes may be decontaminated, shipped to a licensed smelter for melting, or cut up and buried. Estimated survey costs to insure proper confidence in contamination levels for clearance are \$46/ton. The D&D project had not yet been funded at the end of 1999.

DOE has completed the Phase I Feasibility Study required by CERCLA for disposing of the 221-U Facility (DOE 1998). The 221-U Facility is one of five major canyon facilities located in the 200 Area at Hanford. Decisions made regarding the 221-U facility will set regulatory precedents for the other four canyons. Based on the feasibility study, four alternatives were recommended for further consideration:

- Full removal and disposal
- Entombment with internal waste disposal
- Entombment with internal/external waste disposal
- Close in place - collapsed structure

As these alternatives are presented in DOE 1998, only full removal and disposal would produce potentially clearable material. For the other three alternatives, essentially everything would be left in place. In the full removal and disposal alternative, 1,500 yd³ of contaminated equipment and materials would be disposed of and 64,000 yd³ of clean rubble would be either disposed of or recycled (Table D-1, DOE 1998). Since the full removal and disposal option is the most costly of the four alternatives recommended for further analysis, it appears likely at this time that the D&D of the canyons will not generate significant quantities of clearable materials.

Estimates of the quantities of radioactive scrap metals and contamination levels for the Hanford production reactors were made and reported in SC&A 1995a. The radionuclide inventory as of March 1, 1985 (reported in Table 4-14 of SC&A 1995a) is summarized here in Table 3-13.

Additional details on tonnage and contamination in the production reactors is presented in Table 3-14 (from Table 4-16, SC&A 1995a).

It is expected that materials associated with the moderator stack, the thermal shield, and the process tubes will be too contaminated to permit recycling. Some of the metals in the cooling water storage basins and associated cooling water piping and the support buildings are potentially recyclable.

The radioactive waste storage tanks at Hanford contain about 14,000 tons of steel, but this material is expected to be too contaminated for economical recycle.

3.3.4 Idaho National Engineering and Environmental Laboratory (INEEL)

In FY 1999, INEEL recycled 250 tons of structural and stainless steel in the form of I-beams, pipes, angle irons, welded roof trusses, corrugated building siding, etc. Additionally, 190 yd³ of miscellaneous scrap metal (e.g., aluminum, copper) in the form of valves and piping was recycled, as was 3 yd³ of copper wire, 2,600 linear feet of steel fencing, and 4,000 yd³ of concrete (Peterson 1999). This annual level of clearance is expected to continue for the next 10 to 20 years. INEEL does not dismantle the larger components, but rather leaves that to the contractor or scrap dealer. Generally, decontamination techniques are not used prior to clearance. However, in the case of the copper wire, the insulation was burned from the wire prior to clearance and the fumes passed through a HEPA filter system. It is speculative as to whether the insulation was contaminated.

In the case of concrete, two to three scabbling passes may be used to remove surface contamination. The concrete may be in the form of rubble or in blocks of up to 15 tons. INEEL has a rock crusher for concrete size reduction. The crusher is equipped with three magnetic tables to remove the rebar. Crushed concrete is used for road ballast and backfill.

Reliable information on types and levels of contamination is not available. Presumably the nuclides include mixed fission products, especially cesium. No published reports were located

describing details of current or planned recycle activities, although a recent press article noted that INEEL had about 2,000 tons of scrap stainless and carbon steel (Minard 2000). The material was described as “both contaminated and uncontaminated.”

Table 3-13. Estimated Radionuclide Inventory of Hanford B, C, D, DR, F, and H Reactors as of March 1, 1985 (Ci)^a

| Radio-nuclide | Half-Life (yr) | Component | | | | | Total ^c |
|---------------|-----------------------|--------------------------|----------------|---------------|-------------------|---------------|--------------------|
| | | Graphite Stack | Thermal Shield | Process Tubes | Biological Shield | Storage Basin | |
| H-3 | 12.3 | 4,900-8,900 ^b | -- | -- | -- | -- | 4,900-8,900 |
| C-14 | 5,730 | 3,200-4,500 | -- | -- | -- | -- | 3,200-4,500 |
| Ca-41 | 1.0 x 10 ⁵ | 14-190 | -- | -- | 2-4 | -- | 18-152 |
| Co-60 | 5.3 | 30-100 | 4,060-9,980 | 200-350 | -- | 0.5-11 | 4,420-10,426 |
| Ni-59 | 7.5 x 10 ⁴ | 1-2 | 5-7 | 0.1 | -- | 0.002-0.5 | 6-9 |
| Ni-63 | 100 | 28-280 | 580-810 | 10 | -- | 0.27-60 | 686-1,090 |
| Cl-36 | 3.0 x 10 ⁵ | 12-42 | -- | -- | -- | -- | 12-42 |
| Sr-90 | 28.8 | 10 | -- | 0.2 | -- | 0.06-14 | 10-24 |
| Mo-93 | 3,000 | -- | 0.04 | -- | -- | -- | 0.04 |
| Nb-94 | 2.0 x 10 ⁴ | 0.3 | 0.02 | -- | -- | -- | 0.32 |
| Tc-99 | 2.1 x 10 ⁵ | -- | 0.002 | -- | -- | -- | 0.002 |
| Ag-108 | 27 | -- | 0.03 | -- | -- | -- | 0.3 |
| Cs-137 | 30.2 | 30 | -- | -- | -- | 0.12-16 | 30-46 |
| Eu-152 | 13 | 40 | -- | 1.3-1.7 | -- | 0.81-1.4 | 42-46 |
| Eu-154 | 8.5 | 20 | -- | 0.9-1.3 | -- | 0.23-4.2 | 21-28 |
| U-238 | 4.5 x 10 ⁹ | -- | -- | -- | -- | 0.009 | 0.009 |
| Pu-238 | 87.7 | -- | -- | -- | -- | 0.075 | 0.075 |
| Pu-239 | 2.4 x 10 ⁴ | 1 | -- | -- | -- | 0.024-1.6 | 1-2.6 |
| Am-241 | 433 | 0.3 | -- | -- | -- | 0.008-0.5 | 0.3-0.8 |

a Data derived from “Draft Environmental Impact Statement, Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington,” U.S. DOE, DOE/EIS-0119D, March 1989 (DOE 1989).

b The values listed represent the range of values calculated for the B, C, D, DR, F, and H Reactors.

c Some total quantities are rounded off.

Table 3-14. Radioactive Scrap Metal Projections from the Hanford Production Reactors

| Area/Component | Radionuclide/ Type of Contamination | Radiation Level and/or Activity | Metal Waste Type/Quantity (tons) ^a | | | |
|----------------------------------|---|------------------------------------|---|--------------------|------|--------------------|
| | | | Carbon Steel | Stainless Steel | Lead | Other |
| B/C/D/DR/F/H Production Reactors | | | | | | |
| Moderator Stack | Cs-137, Sr-90, Pu-239, Am-241, C-14, H-3 | | | | | 10,800 graphite |
| Thermal Shields | Ni-63 Co-60 | 4,860 Ci 52,140 Ci | | | 479 | 4,714 cast iron |
| Biological Shield - Top & Sides | Ca-41 | 6 Ci | 16,203 | | | |
| Biological Shield - Front & Rear | Ca-41 | 6 Ci | 13,217 | | | |
| Process Tubes | Co-60 | 1,800 Ci | | | | 1,299 aluminum |
| Foundation Plate | | | 50 | | | |
| Support Buildings | | | 1,200 | 445 | | |
| KE/KW Production Reactors | | | | | | |
| Moderator Stack | Cs-137, Sr-90, Pu-239, Am-241, C-14, H-3 | | | | | |
| Thermal Shields | Ni-63 Co-60 | 2,400 Ci 35,000 Ci | | | 240 | 1,886 cast iron |
| Biological Shield | Ca-41 | 30 Ci | 348 | | | |
| Process Tubes | Co-60 Ni-63 | 380 Ci 3,400 Ci | | | | 518 aluminum |
| Foundation Plate | | | 23 | | | |
| Support Buildings | | | 400 | 1,016 | | |

Table 3-14. Radioactive Scrap Metal Projections from the Hanford Production Reactors (continued)

| Area/Component | Radionuclide/ Type of Contamination | Radiation Level and/or Activity | Metal Waste Type/Quantity (tons) ^a | | | |
|--|---|---|---|--------------------|------|-----------------|
| | | | Carbon Steel | Stainless Steel | Lead | Other |
| N Production Reactor ^b | | | | | | |
| Moderator Stack | Cs-137, Sr-90, Pu-239, Am-241 | | | | | |
| Thermal Shields | Ni-63, Co-60 | | | | 120 | 943 cast iron |
| Biological Shield | Ca-41 | | 174 | | | |
| Process Tubes | Co-60, Ni-63 | | | | | 259 aluminum |
| Foundation Plate | | | 11 | | | |
| Support Building | | | 200 | 508 | | |
| B/C/D/DR/F/H/KE/KW/N Fuel Storage Basins | | | | | | |
| Structural Components | | | 450 | | | |
| Miscellaneous | | | | | | |
| Cooling Water Holdup Tanks | Co-60 Ni-63 Sr-90 Cs-137 Pu-239/240 | 6 Ci 36 Ci 0.5 Ci 0.4 Ci 0.9 Ci | 58,800 | | | |
| Cooling Water Holdup Tank Piping | Co-60, Cs-137 | | 15,950 | | | |
| TOTAL ^c | | | 107,026 | 1,969 | 839 | |

a Quantities are totals for all reactors in each group.

b Estimates of RSM from this reactor assume it is similar in size to the KE and KW reactors.

c Total quantities are for all nine reactors and associated systems.

3.3.5 Los Alamos National Laboratory (LANL)

In 1997, LANL identified a total inventory of 2,500 m³ of legacy scrap metal and estimated that the annual generation rate was about 1,200 m³ (Gogol 1997). In addition, about 4,000 m³ is expected from one-time facility upgrading. Most of the scrap metal is carbon steel with very little stainless steel or copper being generated at LANL. The scrap has a bulk density of 1,100 lb/m³ and an average surface area of 0.20 ft²/lb. LANL estimates that about half the scrap is clearable after survey, an additional 25 percent can be cleared after decontamination, and the balance is either volumetrically contaminated or contains inaccessible surfaces and must be treated as LLW. LANL uses sponge jet and high-pressure water treatments for decontamination (Carlson 1999).

Based on the effective bulk density of 1,100 lb/m³ and an annual generation rate of 1,200 m³, it can be estimated that each year, 330 tons is cleared after survey, an additional 165 tons is cleared after decontamination, and 165 tons is buried as LLW.

LANL has a crusher to process concrete. After any required decontamination, the concrete is either "rubble-ized" in place or may be used for fill on site. LANL is too remote to sell the crushed concrete for commercial aggregate. LANL believes that use of the ANSI standard N1312 could double the amount of cleared material (Carlson 1999).

This study found no other reports describing current inventory and projected future generation rates of potentially clearable materials.

3.3.6 Savannah River Site (SRS)

The primary mission of SRS has been to produce Pu-239 and H-3 for the nuclear weapons program. In addition, SRS has produced a variety of radionuclides, including Cf-252, Pu-238, and Am-241, for nuclear medicine, space exploration, and commercial applications (DOE 1998b). Decommissioning activities are scheduled for completion in 2038, but the entire site will remain under the ownership of the Federal Government. The production reactor complex at SRS used to produce the various radionuclides includes a fuel and target fabrication plant, five production reactors, two chemical separations plants, a heavy water rework facility, and waste management facilities (DOE 1990). Dismantling of the five shutdown production reactors (C, K, L, P, and R reactors) should generate large amounts of scrap materials, but the extent to which

these materials are potentially clearable is unknown at this time. Since the reactor buildings for the K, L, and P reactors are reinforced concrete, large but unquantified amounts of that material will be generated, as well. In addition, cooling water is pumped from the Savannah River to reactor area cooling basins through reinforced concrete lines.

Estimates of the radioactive scrap metals expected to be generated from the D&D of these production reactors were presented in SC&A 1995a. Relevant information is summarized in Table 3-15.

Table 3-15. Projections of Radioactive Scrap Metal Generated from D&D of SRS Production Reactors

| Component | Carbon Steel (tons) | Stainless Steel (tons) |
|-------------------------------|---------------------|------------------------|
| Reactor Cooling Pumps | | 816 |
| Heat Exchangers | | 622 |
| Primary Piping | | 500 |
| RCP Flywheels | 89 | |
| Secondary Piping | 500 | |
| Building Structural Materials | 1,000 | |
| Cooling Water Holdup Tanks | 174 | |

While no information on contamination levels is available, it is expected that all of the carbon steel, including the reactor coolant pump flywheels, is potentially clearable. DOE notes that during normal operation, some radioactivity leaks from the primary to the secondary coolant system through the heat exchangers. The expected releases of radionuclides to surface streams through the cooling water from the K, L, and P reactors are summarized in Table 3-16 (DOE 1990). This information provides a qualitative indication of the type of contamination expected on secondary coolant system materials. Whether the stainless steel primary system components are clearable with economically justifiable cleanup procedures is debatable.

Table 3-16. Expected Annual Liquid Releases to Surface Streams from Operation of the K, L, and P Reactors (curies per year)

| Radionuclide | Radioactivity |
|--------------------------------------|-----------------------|
| Tritium | 1.16×10^4 |
| Cobalt-58, Cobalt-60 | 1.00×10^{-3} |
| Cesium-137 | 3.33×10^{-7} |
| Unidentified Beta-Gamma ^a | 1.30×10^{-2} |
| Unidentified Alpha ^b | 3.19×10^{-4} |

a Assumed to be Sr-90.

b Assumed to be Pu-239.

3.4 Methodology for Reduction of Inventory Data

This section describes how the information presented in the preceding sections is analyzed and reduced to forms suitable for estimating collective doses and conducting cost/benefit analyses for various regulatory options.

3.4.1 Gaseous Diffusion Plants

As noted in Section 3.1, the total scrap metal from inventory and D&D within the DOE complex is expected to be about 1.3 million tons. The scrap metal expected from D&D of the gaseous diffusion plants is 737,000 tons (see Tables 3-6 and 3-7). Thus, the diffusion plants contribute 57 percent of the total estimated scrap metal. This inventory estimate assumes that the process buildings with significant amounts of structural steel would be left standing. DOE has indicated that Buildings K-29, K-31, and K-33 at the K-25 Site will be left standing consistent with this assumption. Building K-25 and, probably, Building K-27 will be demolished. To the extent that structural steel is removed and recycled during demolition, the ferrous metals quantity estimates in Tables 3-6 and 3-7 will be understated. D&D plans for the Paducah and Portsmouth Sites are not known, but it is assumed here that they will be handled in a manner consistent with the quantity estimates in Table 3-6. Table 3-6 lists 310,000 tons as "Miscellaneous" metals. For present purposes, it is assumed that 20 percent of this material is copper and 10 percent is aluminum, with the balance being ferrous metals. This rough estimate was based on the description of the miscellaneous materials provided in Table 3-7. Monel and nickel are excluded. The totals in Table 3-6 are restructured in Table 3-17 for data analysis and modeling.

Table 3-17. Modeled Radioactive Scrap Metal Streams Arising from
Decommissioning Gaseous Diffusion Plants (000 tons)

| Category | K-25 Site | Paducah | Portsmouth | GDP Totals |
|----------------------|-----------|---------|------------|------------|
| Ferrous metals/steel | 215 | 131 | 165 | 511 |
| Aluminum | 21 | 14 | 18 | 53 |
| Copper | 42 | 28 | 36 | 106 |
| Site Totals | 278 | 173 | 219 | 670 |

The ferrous metals estimate of 511,000 tons in Table 3-17 is in excellent agreement with a recent DOE estimate that the total ferrous metals to be generated from the D&D of the GDPs is 518,000

tons (Neave 2001). The aluminum and copper estimates are higher than recent estimates by Burns (2001), whose values are 33,000 tons for aluminum and 57,000 tons for copper.

3.4.1.1 Ferrous Metals Inventory Analysis

To estimate the contamination in ferrous metals generated from D&D of the gaseous diffusion plants (Table 3-17), it is assumed here that the contamination distribution described in Figure 3-1 for the Small Scale Metals Recycle Project is applicable to all three diffusion plants. As indicated in Table 3-11, the contamination is dominated by Tc-99, which was introduced into the cascades with reprocessed returns from the production reactors at Hanford and Savannah River. As noted in Section 3.2.2, reactor returns were a major feed source at PGDP, and a significant feed source for K-25; some reactor returns were also fed into the Portsmouth plant (Smith 1984). In the absence of solid information, it is assumed that the contamination levels for technetium and the transuranic elements are the same for all three plants, and that this contamination can be reasonably characterized from the data developed during the Small Scale Metal Recycle Project (SSMRP). The uranium enrichment varies significantly among the various process buildings and among the various diffusion plants, but the relative isotopic abundance of U-234, U-235, and U-238 is not significant since the mass-based dose factors for estimating individual doses for the three isotopes are very similar at 33, 32, and 29 $\mu\text{Sv/yr per Bq/g}$, respectively (NRC 1999).

Based on the information presented in Section 3.2.3.1, including Tables 3-10 and 3-11, it can be estimated that the average fractional contributions of the various radionuclides to the total activity is:

- U-235: 0.008 (1.5 pCi/g steel)
- U-238: 0.11 (19 pCi/g steel)
- U-234: 0.17 (30.5 pCi/g steel)
- Np-237: 0.0014 (0.25 pCi/g steel)
- Pu-238: 0.00028 (0.05 pCi/g steel)
- Pu-239: 0.0006 (0.1 pCi/g steel)
- Am-241: 0.00056 (0.1 pCi/g steel)
- Tc-99: 0.71 (125 pCi/g of steel)
- Total: (176.5 pCi/g of steel)

The mean value of the surface activities for the Building 31 SSMRP was 148,000 dpm/100 cm^2 (Kerr et al., 1999). To convert these surface activities to specific activities, it was assumed for this report that 148,000 dpm/100 cm^2 is equivalent to 176.5 pCi/g of steel. This assumption is

consistent with the fact that the surface activity and the specific activity were both developed under the SSMRP.

Using the distribution of the 2,026 surface contamination measurements from Figure 3-1, the cumulative mass of ferrous metals associated with specific activities was calculated with the results shown in Figure 3-3. To develop this curve, it was assumed that the surface contamination measurements were uniformly distributed over the 511,000 tons (464,000 metric tons, see Table 3-17), and the activity for the i th surface contamination measurement was equal to i th measurement $\times 176.5 \div 148,000$. From this figure, it can be seen that about 78 percent of the material would have a total activity of less than 120 pCi/g.

Details summarizing mass and activity calculations for the full range of surface contamination measurements are included in Table 3-18. Additional detail by individual radionuclide is included in Appendix G (which also includes existing inventory at the GDP sites).

Obviously, there are substantial uncertainties in these estimates related both to tonnage and contamination. The tonnage estimates are based on a 1991 study by Ebasco, which considered the K-25 Site in some detail and then extrapolated these estimates to the other two gaseous diffusion plants based on scaling factors. Additionally, the Ebasco studies assumed that significant quantities of steel would remain with structures that were not razed. Another element contributing to uncertainty is the fact that the Ebasco study did not provide a detailed breakdown of all metals by type. For example, see the above discussion in Section 3.4.1 on "Miscellaneous" metals. At the present time, plans at the K-25 Site call for leaving Buildings K-29, K-31, and K-33 intact as industrial sites. Buildings K-25 and K-27 will be razed. It is not known whether any structural steel from these two buildings will be available for recycle or whether the buildings will be demolished and disposed of in place. All of these unknowns can affect the materials estimates, particularly those for concrete and ferrous metals. Given these uncertainties, it is the author's professional judgement that uncertainty in the mass estimates is ± 30 percent.

The contamination estimates are based on data generated from the Small Scale Metals Recycle Project. Of particular concern are the estimates for Tc-99. During the separation process, the relatively light-weight Tc-99 isotope tends to move with U-235 up the cascade (NAS 1996). Thus, technetium concentrations may be higher both on a relative and an absolute basis for cells near the cascade outlet. To estimate the impact of this uncertainty, a test case was developed assuming that 90 percent of the contamination was Tc-99, that all measurements in Figure 3-1

were increased by a factor of five, and the average Tc-99 content was 625 pCi/g. The results are compared with base case in Table 3-19.

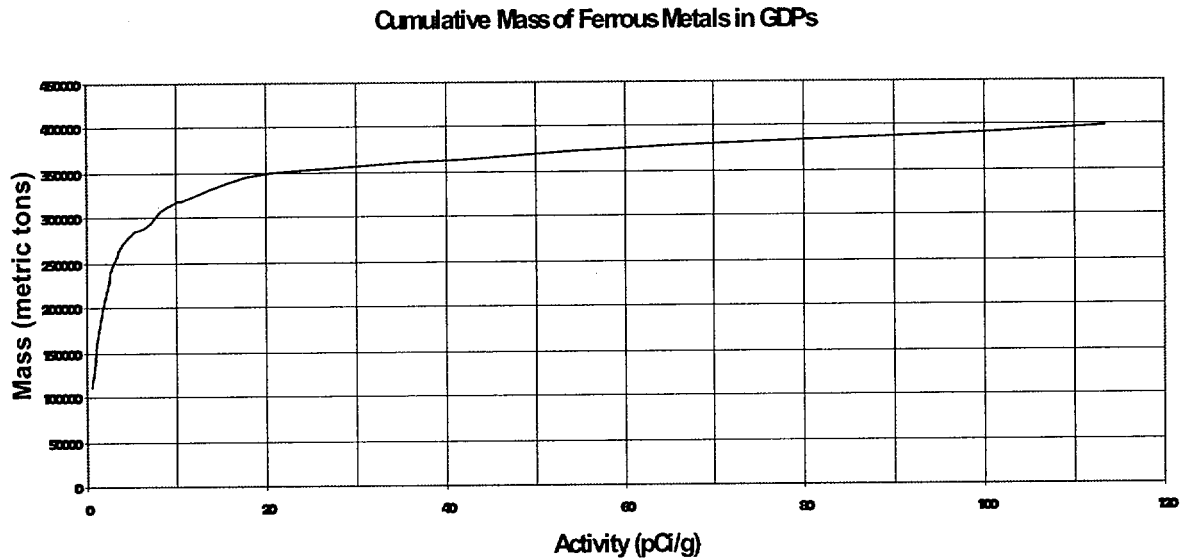


Figure 3-3. Cumulative Fraction of Ferrous Metal Scrap at Various Activity Levels

Comparing the high technetium case with the base case, it can be seen the total curies are roughly doubled.

As indicated in Table 3-3, substantial inventories of scrap metals currently exist at the three gaseous diffusion plants, including 92,355 tons of ferrous metals scrap. The contamination levels for this scrap are not documented, but a significant fraction is presumed to have been generated during the Cascade Improvement and Cascade Upgrade Programs (CIP/CUP) in the early 1980s. Some contamination data are available from a declassified excerpt of a report describing measurements on scrap metal at PGDP. Values obtained from samples representative of 9,980 tons of steel scrap are summarized in Table 3-20 (PGDP 1983). The measurements are taken from samples, which had been decontaminated with an ammonium carbonate solution and “are considered to be a reasonable approximation of the levels to be expected in the Paducah CIP/CUP steel scrap.”

Table 3-18. Calculated Cumulative Mass of Ferrous Metals in Gaseous Diffusion Plants as a Function of Activity Level

| Surface Activity (dpm/100 cm ²) | Mass per Bin (tons) | Total Activity (Ci) |
|--|------------------------|------------------------|
| 0 - 1,000 | 123,588 | 0.07 |
| 1,000-2,000 | 95,844 | 0.15 |
| 2,000-3,000 | 55,489 | 0.15 |
| 3,000-4,000 | 25,222 | 0.09 |
| 4,000-5,000 | 15,133 | 0.07 |
| 5,000-6,000 | 5,044 | 0.03 |
| 6,000-7,000 | 10,089 | 0.07 |
| 7,000-8,000 | 12,611 | 0.10 |
| 8000-9,000 | 8,828 | 0.08 |
| 9,000-10,000 | 2,522 | 0.03 |
| 10,000-20,000 | 25,222 | 0.40 |
| 20,000-30,000 | 12,611 | 0.34 |
| 30,000-40,000 | 7,567 | 0.28 |
| 40,000-50,000 | 10,089 | 0.48 |
| 50,000-60,000 | 7,567 | 0.44 |
| 60,000-70,000 | 5,044 | 0.35 |
| 70,000-80,000 | 5,044 | 0.40 |
| 80,000-90,000 | 5,044 | 0.46 |
| 90,000-100,000 | 6,306 | 0.64 |
| 100,000-200,000 | 22,700 | 3.64 |
| 200,000-300,000 | 7,567 | 2.02 |
| 300,000-400,000 | 10,089 | 3.77 |
| 400,000-500,000 | 5,044 | 2.42 |
| 500,000-600,000 | 3,783 | 2.22 |
| 600,000-700,000 | 1,261 | 0.88 |
| 700,000-800,000 | 2,522 | 2.02 |
| 800,000-900,000 | 252 | 0.23 |
| 900,000-1,000,000 | 3,783 | 3.84 |
| 1,000,000-2,000,000 | 7,567 | 12.12 |
| 2,000,000-3,000,000 | 3,783 | 10.10 |
| 3,000,000-4,000,000 | 1,261 | 4.71 |
| 4,000,000-5,000,000 | 504 | 0.23 |
| 5,000,000-6,000,000 | 1,261 | 1.44 |
| 6,000,000-7,000,000 | 252 | 0.06 |
| 7,000,000-8,000,000 | 0 | 0.00 |
| 8,000,000-9,000,000 | 0 | 0.00 |
| 9,000,000-10,000,000 | 0 | 0.00 |
| 10,000,000-20,000,000 | 504 | 0.23 |

Table 3-19. Comparison of Base Case Clearable Tons and Curies with High Technetium Case

| Base Case | | High Technetium Case | |
|-----------------|--------|----------------------|--------|
| Cumulative Tons | Curies | Cumulative Tons | Curies |
| 124,000 | 0.1 | 124,000 | 0.3 |
| 330,000 | 0.6 | 275,000 | 1 |
| 422,000 | 3 | 392,000 | 6 |

Table 3-20. Analysis of PGDP Steel Scrap Samples

| Source | Uranium (ppm) | Neptunium (ppb) | Plutonium (ppb) | Technetium (ppb) |
|--------------------------|---------------|-----------------|-----------------|------------------|
| Inlet Tube Sheet | 97 | 7.9 | <0.006 | 62 |
| Outlet Tube Sheet | 145 | 12.9 | 0.009 | 54 |
| Intermediate Tube Sheet | 17 | 1.29 | <0.004 | 11 |
| Tube Bundle Core | 15 | <0.28 | <0.003 | 1.9 |
| Tube Bundle Strut Braces | 20 | 4 | <0.003 | 7.2 |
| J-Brackets | 14 | 5.3 | <0.002 | 1.1 |
| Jack Screws | 736 | 36.3 | <0.002 | 41 |
| Converter Shell | 14 | 1 | <0.001 | 13 |
| Flange | 100 | 1.8 | <0.002 | 0.78 |

The same report quoted average values for the steel scrap contaminants as:

- U: 31 ppm
- Np: 2.3 ppb
- Pu: 0.002 ppb
- Tc: 17 ppb

Converting these assays to units of pCi/g (assuming that the uranium is U-238 and the Pu is Pu-239) provides values that are similar to those obtained during the Small Scale Metals Recycle Project (Table 3-11) as shown by the following comparison:

| Source | U (pCi/g) | Np (pCi/g) | Pu (pCi/g) | Tc (pCi/g) |
|---|-----------|------------|------------|------------|
| Small Scale Metals Recycle Project (K-25) | 51 | 0.25 | 0.15 | 125 |
| PGDP CIP/CUP Scrap | 10 | 2 | 0.12 | 289 |

This similarity is expected since the operations at K-25 and Paducah are analogous. Given this close similarity, it was decided to treat the ferrous metals in the diffusion plant scrap yards in the same manner as ferrous metals from diffusion plant D&D.

Using the methodology outlined above, the amounts of radioactivity associated with the various nuclides contained in 92,355 tons of ferrous metals in inventory at the three GDPs (see Table 3-3) were estimated and added to similar values obtained for the ferrous metals from D&D. Results are summarized in Appendix G.

3.4.1.2 Aluminum Inventory Analysis

PGDP reported results of assays on aluminum alloy compressor blades as summarized in Table 3-21 (PGDP 1983).

To use these data to characterize aluminum scrap in inventory at the gaseous diffusion plants, it was assumed that the contamination was uniformly distributed over the range for each element. This was done since the available information in the declassified excerpt of PGDP 1983 was insufficient to determine how to weight the results in Table 3-21. The uranium was assumed to be present as U-238, and the plutonium was assumed to be Pu-239. The fractional activity mix based on mid-range values is:

- U-238: 0.240
- Pu-239: 0.004
- Tc-99: 0.734
- Np-237: 0.022

Table 3-21. Assays of Aluminum Alloy Compressor Blades at PGDP

| Source | U (ppm) | Pu (ppb) | Tc (ppb) | Np (ppb) |
|--|---------|----------|----------|----------|
| C-337-2.2 | 544 | 0.08 | 30 | 32 |
| C-331-2.2, C-335-1.1, C-335-4.6 ^a | 868 | <0.05 | 73 | 56 |
| C-332-2.3 | 219 | <0.05 | 12 | <5 |
| C-335-2.4 | 899 | <0.05 | 68 | 10 |
| Dissolved Blade | 1290 | <0.05 | 40 | 10 |
| Dissolved Blade | 842 | <0.05 | 49 | <5 |
| Dissolved Blade | 108 | <0.05 | 22 | <5 |

a Blade analyses for these cells are an average of the concentrations found on samples from 23 previous locations (PGDP 1983).

The total available tonnage was assumed to be 59,000 tons (53,000 tons from D&D per Table 3-17 and 6,137 tons from existing inventory per Table 3-3). Quantities of radioactivity

associated with various quantities of aluminum scrap are summarized in Table 3-22 (see Excel spreadsheet Pgdp_s~1.xls for details).

Table 3-22. Cumulative Quantities of DOE Aluminum Scrap Metal and Associated Radioactivity

| Cumulative Fraction (%) | Uranium Contam. (pCi/g) | Plutonium Contam. (pCi/g) | Technetium Contam. (pCi/g) | Neptunium Contam. (pCi/g) | Cumulative Contam. (pCi/g) | Cumulative Mass (tons) | Cumulative Radioactivity (Ci) |
|-------------------------|-------------------------|---------------------------|----------------------------|---------------------------|----------------------------|------------------------|-------------------------------|
| 10 | 76.2 | 3.29 | 307 | 7.13 | 394 | 5900 | 2.11 |
| 20 | 116 | 3.48 | 411 | 10.7 | 541 | 11,800 | 5.79 |
| 30 | 156 | 3.67 | 515 | 14.3 | 688 | 17,700 | 11.1 |
| 40 | 196 | 3.85 | 618 | 17.9 | 835 | 23,600 | 17.9 |
| 50 | 235 | 4.04 | 722 | 21.5 | 983 | 29,500 | 26.3 |
| 60 | 275 | 4.23 | 825 | 25.1 | 1,130 | 35,400 | 36.3 |
| 70 | 315 | 4.41 | 929 | 28.7 | 1,277 | 41,300 | 47.8 |
| 80 | 355 | 4.60 | 1,032 | 32.3 | 1,424 | 47,200 | 61.0 |
| 90 | 395 | 4.79 | 1,136 | 35.9 | 1,571 | 53,100 | 75.7 |
| 100 | 434 | 4.97 | 1,240 | 39.5 | 1,718 | 59,000 | 92.0 |

3.4.1.3 Copper Inventory Analysis

No detailed information characterizing copper contamination was uncovered in the course of this study. A spreadsheet developed by DOE (msc_mass.xls)¹² assumes that copper scrap and steel scrap have the same average assay, citing PGDP 1983 as the reference. Corroborating information supporting this assumption was not available in the declassified excerpt available for the present study. However, in lieu of any other information, this assumption was accepted as a placeholder for analytical purposes. Based on the steel assays listed below in Table 3-23 (from PGDP 1983, Table 1), a cumulative distribution function for contaminants in copper was constructed.

¹² This spreadsheet was provided by R. Sheely, K-25 Site, in October 1999.

Table 3-23. Assumed Levels of Contamination in
Copper Scrap at Gaseous Diffusion Plants

| Uranium (ppm) | Neptunium (ppb) | Plutonium (ppb) | Technetium (ppb) |
|---------------|-----------------|-----------------|------------------|
| 97 | 7.9 | <0.006 | 62 |
| 145 | 12.9 | 0.009 | 54 |
| 17 | 1.29 | <0.004 | 11 |
| 15 | <0.28 | <0.003 | 1.9 |
| 20 | 1.4 | <0.003 | 7.2 |
| 14 | 5.3 | <0.002 | 1.1 |
| 736 | 36.3 | <0.002 | 41 |
| 14 | 1.0 | <0.001 | 13 |
| 100 | 1.8 | <0.002 | 0.78 |
| 31 (avg.) | 2.3 (avg.) | 0.002 (avg.) | 17 (avg.) |

This distribution function is presented in Table 3-24.

Table 3-24. Constructed Distribution for Radionuclides in Copper

| Radionuclide | Fractional Distribution | Concentration Range (ppb) | Mid-Range Activity (pC/g) | Upper End Activity (pC/g) |
|--------------|-------------------------|---------------------------|---------------------------|---------------------------|
| U-238 | 0.556 | 14,000-20,000 | 5.72e+00 | 6.73e+00 |
| | 0.222 | 97,000-100,000 | 3.30e+01 | 3.37e+01 |
| | 0.222 | 145,000-736,000 | 1.48e+02 | 2.48e+02 |
| Np-237 | 0.556 | 0.28-1.8 | 7.06e-01 | 1.27e+00 |
| | 0.222 | 5.3-7.9 | 4.94e+00 | 5.58e+00 |
| | 0.222 | 12.9-36.3 | 1.77e+01 | 2.56e+01 |
| Tc-99 | 0.556 | 0.78-11 | 1.02e+02 | 1.87e+02 |
| | 0.222 | 13-41 | 4.58e+02 | 6.96e+02 |
| | 0.222 | 54-62 | 9.85e+02 | 1.05e+03 |
| Pu-239 | 0.556 | <0.001-<0.003 | <1.24e-01 | <1.87e-01 |
| | 0.222 | <0.003-<0.004 | <2.18e-01 | <2.49e-01 |
| | 0.222 | <0.006-0.009 | <4.66e-01 | 5.60e-01 |
| All Nuclides | 0.556 | | 1.08e+02 | 1.95e+02 |
| | 0.222 | | 4.97e+02 | 7.36e+02 |
| | 0.222 | | 1.15e+03 | 1.33e+03 |

Tables 3-3 and 3-17 show that there are about 112 tons of copper scrap currently in inventory and another 106,000 tons expected from D&D of the gaseous diffusion plants. Using the distribution in Table 3-24, the cumulative radioactivity associated with various copper tonnages was estimated. Results are summarized in Table 3-25 (see Excel spreadsheet Pgdp_s~1.xls for details).

Table 3-25. Estimated Quantities of Radioactivity Associated with DOE Copper Scrap

| Cumulative Mass (tons) | Cumulative Radioactivity (Ci) | U-238 Radioactivity (Ci) | Np-237 Radioactivity (Ci) | Pu-239 Radioactivity (Ci) | Tc-99 Radioactivity (Ci) |
|------------------------|-------------------------------|--------------------------|---------------------------|---------------------------|--------------------------|
| 58,951 | 5.8 | 0.31 | 0.038 | 0.0066 | 5.4 |
| 82,532 | 16 | 1.0 | 0.14 | 0.011 | 15 |
| 106,112 | 41 | 4.2 | 0.52 | 0.021 | 36 |

About 88 percent of the estimated activity in the copper scrap is associated with Tc-99.

3.4.2 Y-12 Scrap Yard

The contamination distribution in Figure 3-2 was used as the basis for estimating levels of contamination on materials in the Y-12 scrap yard. The masses of metals were obtained from Table 3-3 and the fractional activity distribution was assumed to be 54.7 percent U-238, 2.1 percent U-235, and 43.2 percent U-234 (Kerr et al. 1999). Using the distribution of surface activities and this activity mix, the amount of ferrous metals potentially clearable from a total of 11,242 tons was estimated. To convert the surface activities to volumetric activities, a mass to surface ratio of 110 lb/m² (4.99 g/cm²) was used (Anderson et al. 1993). The clearable curies for each tonnage increment were then calculated. The results are summarized in Table 3-26 (see Excel spreadsheet y12scrap3.xls for details).

Table 3-26. Potentially Clearable Tons and Curies from Ferrous Metals in Y-12 Scrap Yard

| Surface Activity (dpm/100 cm ²) | Cumulative Activity (Curies) | | | | Cumulative Ferrous Metals (tons) |
|---|------------------------------|--------|-------|-------|----------------------------------|
| | U-238 | U-235 | U-234 | Total | |
| <250 | 0.014 | 0.001 | 0.011 | 0.026 | 4,400 |
| <2,200 | 0.16 | 0.0062 | 0.13 | 0.3 | 8,700 |
| <5,0000 | 0.19 | 0.0073 | 0.15 | 0.35 | 8,900 |
| <25,000 | 0.72 | 0.027 | 0.57 | 1.3 | 9,800 |
| <1,000,000 | 32 | 1.2 | 26 | 59 | 11,242 |

It should be noted that the amount of ferrous metals in the Y-12 scrap has increased to about 20,000 tons based on the recent DOE data call as shown in Table 3-5. Since no information on the contamination distribution was available for the more recent survey, the higher totals were not included here.

3.5 Concrete Recycling

While large quantities of reinforced concrete exist within the DOE complex, sufficient data are not available to characterize the extent to which this material might be available for recycle. In some instances, DOE has elected to leave structures standing for re-industrialization projects; in other cases, structures have been demolished and used as fill; and DOE is considering in-place rubbleization of other structures. Localized areas of contamination will likely be removed by scabbling or similar processes before ultimate disposal of the remainder.

Data presented in Table 3-12 indicated that the volume-weighted radioactivity from Buildings K-1131 and K-1430 at the K-25 Site is 0.8 Bq/g. Similarly, the fill material from Buildings K-724 and K-725 contained about a maximum of 0.19 Bq/g (Section 3.2.3.4). Table 3-9 provides estimates of the fraction of the building surfaces and floors in the K-25 facilities that are contaminated and indicates that the contamination can range from 5,000 to 1 million dpm/100 cm². However, available information from the published literature identified in this study does not identify masses of concrete and contamination distributions in sufficient detail to permit a quantitative analysis of the kinds and quantities of radioactivity associated with concrete tonnages resulting from D&D.

4.0 DEPARTMENT OF DEFENSE INVENTORIES

This chapter provides information on the U.S. Department of Defense facilities, including those that are licensed by the NRC and those that are not. Most DOD facilities using potentially clearable materials are licensed by the NRC and cover the same spectrum of operations as other non-fuel-cycle materials licensees discussed in Chapter 3, e.g., hospitals, research laboratories, users of sealed source gauges, and irradiators. A total of 611 materials licenses (or permits under Master Materials Licenses) are currently issued to DOD. Approximately three-fourths of these licenses/permits are for sealed source users who will not generate radioactive materials during normal operations. Naval nuclear reactor propulsion facilities are not licensed by the NRC. When nuclear ships are decommissioned, the reactor compartments are cut from the hull, sealed, and shipped for burial at Hanford. The ship hulls are scrapped. Dismantling of a typical nuclear submarine produces about 1,000 tons of ferrous metals, 40 tons of aluminum, 245 tons of copper (and alloys), and 900 tons of lead. Depleted uranium used by the military as armor-piercing ammunition and as tank armor are also not licensed by the NRC. Depleted uranium munitions are being phased out by the Navy and the Air Force. Obsolete or damaged depleted uranium tank armor, which is steel encased, is disposed of at the Nevada Test Site, because of its classified nature. Eventually, about 5,000 M1A1 Abrams Tanks will be upgraded to include depleted uranium armor.

4.1 Introduction

Most Department of Defense (DOD) users of nuclear materials are licensed by the U.S. Nuclear Regulatory Commission. DOD licensees vary widely in function and size and include hospitals, laboratories, R&D facilities, proving grounds, bombing and gunnery practice ranges, nuclear reactors, weapons manufacturing and storage facilities, and missile launch sites. The U.S. Navy and the U.S. Air Force hold Master Materials Licenses from the NRC, and each organization issues permits under these master licenses. The arrangement is similar to that which the NRC has with Agreement States. The Navy Master Materials License is managed for NRC by Region 2 in Atlanta, Georgia, while the Air Force Master Materials License is managed by Region 4 in Arlington, Texas. The NRC issues individual licenses to each Department of the Army entity using radioactive materials. Naval reactors for ship propulsion and related support facilities are not licensed by the NRC, nor are depleted uranium (DU) armaments used by the various armed services.

4.2 U.S. Navy Materials Licensees

The Naval Radiation Safety Committee located in Crystal City, Virginia, manages nuclear materials permits within the U.S. Navy. As of March 2000, the Navy had 139 Naval Radioactive Material Permits active under its master license. Each permit contains provisions similar to a nuclear materials license issued by the NRC (Fuller 2000). The quantities of materials actually used by the permittees are well below the permit limits. Of the 139 permits, 2 are issued for operations in U.S. territories (Guam), 8 for operations in other countries, and 4 are assigned to ships. The remaining 125 permits are assigned to locations in the United States, including 19 states and the District of Columbia. The three states with the largest numbers of permits are California (27), Maryland (18), and Virginia (16). Table 4-1 categorizes the permits by type of application.

Table 4-1. Description of U.S. Navy Radioactive Material Permits

| Type Code | Description | Number of Permits |
|-----------|--|-------------------|
| 1 | Nuclear Medicine (limited scope) | 13 |
| 2 | Nuclear Medicine (broad scope) | 1 |
| 4 | Research (non-human use) | 7 |
| 6 | Navy Drug Screening Laboratories | 3 |
| 7 | Gas Chromatographs | 2 |
| 8 | Special Nuclear Material (<200 g) | 1 |
| 9 | Other (dosimeter calibration) | 1 |
| A | Radiography | 14 |
| B | General Industrial (not otherwise coded) | 11 |
| C | Calibrator (>100 Ci) | 18 |
| E | Type A (broad scope) | 3 |
| F | Type B (broad scope) | 1 |
| H | Special Nuclear Material (unsealed, < critical mass) | 1 |
| I | Portable Gauges | 12 |
| J | Analytical Measuring Instruments | 21 |
| K | Gas Chromatographs | 1 |
| L | DU Munitions Testing (outdoors/indoors) | 4 |
| M | Subcritical Assemblies | 1 |
| N | RTG Power Sources | 2 |
| P | Fixed Gauges | 1 |
| Q | Irradiators | 1 |
| R | Buried Waste (NEESA) | 1 |

Table 4-1. Description of U.S. Navy Radioactive Material Permits (continued)

| Type Code | Description | Number of Permits |
|-----------|--|-------------------|
| S | Source Material | 3 |
| T | Radioactive Commodities Handling and Storage | 11 |
| V | Special Nuclear Material (< 200 g) | 1 |
| W | Research and Development | 4 |

Permits with Type Codes 7, 9, A, C, I, J, K, N, P, Q, and T are assumed to involve sealed sources. The balance includes 55 permits world-wide of which 50 are within the United States. Of the 50 U.S. permits, 15 involve nuclear medicine and drug screening, 11 are general industrial, 8 are for research and development activities, 4 pertain to DU munitions testing, 4 cover broad scope licenses, 3 involve source materials, and 3 involve special nuclear materials. The other two permits are for buried waste and sub-critical assemblies.

4.3 U.S. Air Force Materials Licensees

Management of nuclear material permits within the U.S. Air Force is assigned to the USAF Radioisotope Committee headquartered at Bolling Air Force Base, Washington, DC. The Air Force has issued 376 permits under its Master Materials License as of June 2000 (Coleman 2000). This large number of permits results from the fact that each chemical air monitor and chemical air detector is individually permitted. Monitor and detector permits involve sealed sources. A listing of the types of permits is included as Table 4-2.

Items marked with an asterisk in Table 4-2 indicate that the permit involves a sealed source of radioactivity. Under these permits, there is virtually no potential for contamination during normal service. The static eliminators are not truly sealed sources, but because of their design and quantity of contained radioactivity, they have little potential for contamination. Many static eliminators use Po-210, which has a half-life of 138 days and decays to stable Pb-206. Thus, any contamination can be eliminated by simply allowing the decay process to occur. Based on the permit descriptions, only about 41 facilities might be sources of potentially clearable materials and, of that number, 12 are medical institutions, which are discussed in detail in Chapter 2 (Section 2.5).

Table 4-2. Permits under U.S. Air Force Master Materials License

| Permit Type | Number of Permits |
|---------------------------------------|-------------------|
| Academic Type A Broad | 1 |
| Academic Type C Broad | 1 |
| Byproduct Material (storage only) | 1 |
| Calibration Services | 42* |
| Chemical Agent Monitor | 239* |
| Decontamination Services | 2 |
| Distribution Type B Broad | 2* |
| Irradiators | 4* |
| Measurement System | 10* |
| Medical Institution | 12 |
| Portable Gauges | 12* |
| R&D Other | 3 |
| R&D Type A Broad | 2 |
| R&D Type C Broad | 1 |
| Radioisotope Thermoelectric Generator | 1* |
| Source Material | 12 |
| Special Nuclear Material | 5 |
| Static Eliminator | 25* |
| Waste Disposal Service | 1 |

* Sealed Source User

The Air Force operates a radioactive materials recycling program through Wright Patterson Air Force Base (WPAFB) to reduce the quantities of materials that must be disposed of as LLW (<http://abwem.wpafb.af.mil/em/emb/radiation>). This facility acts as a clearinghouse for Air Force installations worldwide. If the material is recyclable, WPAFB contracts for the recycling. For example, Am-241 may be returned to the sealed source manufacturer for processing. A listing of currently recycled materials is presented in Table 4-3.

WPAFB also maintains, at the website referred to above, a listing of all parts (e.g., compasses, static eliminators, etc.) that contain radioactivity.

Table 4-3. Radionuclides Currently Recycled by the U.S. Air Force

| Radionuclide | Form | Examples |
|------------------|-----------------------------|--|
| Tritium (H-3) | Gaseous only (no oxides) | Compasses, Wrist Watches, Markers (e.g., exit signs, buttons, indicators) |
| Depleted Uranium | No other metals attached | Counterweights, Non-Explosive Munitions (penetrators only) |
| Krypton-85 | Gas | Electron Tubes, Nucleonic Oil Indicators, RADIAC Check Sources |
| Americium-241 | Solid | Smoke Detectors, M8A1 Chemical Agent Alarms |
| Polonium-210 | Solid | Static Elimination Devices (typically manufactured by NRD or NPL). No 3M devices. |
| Cesium-137 | Solid | Exempt Distribution Check Sources (AN/PDR 27T, button sources) less than 9.0 mCi |

4.4 U.S. Army Materials Licensees

As of May 1999, the NRC had issued 96 materials licenses to the Department of the Army¹³. In some cases (e.g., Aberdeen Proving Ground), multiple licenses exist to cover the activities of different entities at the site. In other cases, a single license may involve multiple user locations. For example, license 08-01738-02 granted to the Walter Reed Army Medical Center in Washington, DC, covers seven user locations in Maryland. A breakdown of licenses by NRC program code is presented in Table 4-4.

Assuming that NRC licenses described by program codes 3120, 3121, 3123, 3124, 3222, 3225, 3240, 3310, 3320, 3511, 3520, 3521, and 22150 involve sealed sources, a total of 35 licenses were categorized accordingly. Of the remaining 61 licenses, 20 involve R&D facilities, 20 cover the use of source material, 14 appertain to hospital activities, and the remaining 7 cover miscellaneous uses.

The Army under the aegis of the Safety/RAD Waste Team of the Operations Support Command, Rock Island, Illinois, handles disposal of all radioactive waste for all generator sites within DOD except those from the Naval Nuclear Propulsion Program (Graham 2001). In FY-1999, 112,993 ft³ of LLW was handled; 9 percent was operational waste and the balance was cleanup waste. In FY-2000, a total of 117,056 ft³ of waste was handled, of which 4 percent was operational waste. Waste components include radium diodes/gauges, medical wastes from military hospitals, and

¹³ Data for this section were obtained from the NRC database of materials licensees, which was provided to S. Cohen and Associates in May 1999 as an electronic data file.

DU ammunition. Most waste disposal is at licensed commercial facilities; some classified waste (e.g., DU armor) is disposed of at the Nevada Test Site.

Table 4-4. U.S. Army Nuclear Materials Licenses Categorized by Program Code

| Program Code | Program Code Description | Number of Licenses |
|--------------|--|--------------------|
| 1100 | Academic, Type A Broad | 1 |
| 2110 | Medical Institution Broad | 4 |
| 2120 | Medical Institution Limited | 10 |
| 3120 | Measuring Systems Fixed Gauges | 3 |
| 3121 | Measuring Systems Portable Gauges | 12 |
| 3123 | Measuring Systems Gas Chromatographs | 2 |
| 3124 | Measuring Systems Other | 2 |
| 3222 | Instrument Calibration Service | 1 |
| 3225 | Other Services | 2 |
| 3234 | Waste Disposal Service Processing | 1 |
| 3240 | General License Distribution | 1 |
| 3310 | Industrial Radiography Fixed Location | 2 |
| 3320 | Industrial Radiography Temp. Job Sites | 1 |
| 3511 | Irradiators Other <10,000 Ci | 1 |
| 3520 | Irradiators Self-Shielded >10,000 Ci | 4 |
| 3521 | Irradiators Other >10,000 Ci | 1 |
| 3610 | Research & Development Type A Broad | 13 |
| 3611 | Research & Development Type B Broad | 1 |
| 3612 | Research & Development Type C Broad | 1 |
| 3620 | Research & Development Other | 5 |
| 3800 | Byproduct Material Possession Only | 3 |
| 11200 | Source Material Other <150 kg | 1 |
| 11220 | Source Material Military Munitions Indoor | 4 |
| 11221 | Source Material Military Munitions Outdoor | 2 |
| 11300 | Source Material Other >150 kg | 12 |
| 11800 | Source Material Possession Only | 1 |
| 21320 | Critical Mass Material Other Than Universities | 1 |
| 22111 | SNM U-235 and/or U-233 Unsealed | 1 |
| 22150 | SNM Pu Sealed Sources Less Than Critical Mass | 3 |
| TOTAL | | 96 |

4.5 Naval Nuclear Propulsion Program

The Naval Nuclear Propulsion Program is responsible for all nuclear-powered submarines and surface ships. By 1994, the U.S. Navy had 99 nuclear-powered submarines and 13 nuclear-powered surface ships in operation (USN 1996). Of the 13 surface ships, several were nuclear-powered cruisers. The remaining surface ships were nuclear-powered aircraft carriers. The Naval Nuclear Propulsion Program has relied on a number of Navy and Department of Energy (DOE) facilities in order to train ship's crews and to repair propulsion plant components. These facilities include nuclear power plant prototype sites (e.g., the A1W prototype at the Idaho National Engineering Laboratory) for training purposes, and nuclear repair facilities, including naval nuclear shipyards, and other repair facilities including tenders. No documents were located that describe recycling from these facilities. The NRC does not regulate activities related to this program.

The Navy began to decommission and recycle obsolete nuclear-powered ships as part of its Submarine Recycling Program at the Puget Sound Naval Shipyard in 1990 beginning with the USS Scamp (<http://chinfo.navy.mil/navpalib/ships/submarines/centennial/chrono.html>).¹⁴ This program was renamed the Nuclear Powered Ship and Submarine Recycling Program (NPSSRP) in 1992 (Boing 1998).

Disposal of submarines begins with ship inactivation at Puget Sound Naval Shipyard, defueling of the nuclear reactor, and reactor compartment removal. The reactor compartment is removed from the submarine by cutting and capping or plugging any reactor compartment bulkhead penetrations. The hull section containing the reactor compartment is then separated fore and aft from the submarine pressure hull. Finally, the separated submarine reactor compartment is packaged for transport to a disposal site. As of April 1999, the U.S. Navy had shipped 79 reactor compartment packages (representing 77 submarines and 1 cruiser) to the Department of Energy's Hanford site for disposal (USN 1999).

Disposal of cruisers is different from disposal of submarines in that cruisers have two reactor compartments, and the cruiser reactor is contained in a compartment that is not an integral part of

¹⁴ Nuclear-powered submarines had been dismantled prior to 1990, but not as part of a formal recycling program.

the ship's hull. To remove the cruiser reactor compartment, the ship's surrounding structure is cut away, and the compartment is encased in a steel containment structure.

Subsequent to reactor compartment removal, the remaining ship (submarine or cruiser) may be dismantled for reuse, recycling, or disposal. Since dismantlement may not occur immediately, the fore and aft sections of the submarine pressure hulls may be welded back together and the vessel refloated while awaiting recycle. The recycling process involves stripping the ship's interior, including removal of hazardous materials. The hull may then be cut into sections. Alternatively, large hull sections may be removed and then stripped of internal components. More recently, the U.S. Navy has used a combination of the two methods. According to USN 1999, "[t]he disposal of nuclear powered ships is accomplished using proven technology and "...cycling the rest of the ship involves straightforward disassembly, component removal, heavy lifting, packaging, and transporting."

No documents were located that describe how the U.S. Navy clears materials for reuse or recycling. The U.S. Navy has issued general guidance in this area, including NAVSEA 389-0288, Radiological Controls for Shipyards, and 389-0053, Radiological Controls, both of which are classified. Other documents may exist that detail clearance requirements for the submarine and cruiser dismantlement and disposal program.

A typical submarine recycling generates about 2,500,000 pounds of HY-80 steel, 600,000 pounds of carbon steel; 20,000 pounds of sheet metal; 110,000 pounds of stainless steel; 8,000 pounds of galvanized steel; 85,000 pounds of aluminum; 250,000 pounds of brass/bronze; 150,000 pounds of monel; 90,000 pounds of copper; 6,500 pounds of zinc; and up to 1,800,000 pounds of lead (USN 1999).

A typical cruiser generates about 11,000,000 pounds of hull steel and furnishings and about 1,000,000 pounds of aluminum superstructure (USN 1999).

Weights of the removed reactor compartments are stated at 1,130 tons for pre-Los Angeles class submarines, 1,680 tons for Los Angeles class submarines, 2,750 tons for Ohio class submarines, 2,250 tons for each of two Long Beach cruiser reactor compartments, and 1,400 tons for reactor compartments from other cruisers (USN 1996).

The available documents do not provide materials composition for the removed reactor compartments. However, submarine reactor compartments use the same pressure hull steel (e.g., HY-80 carbon steel) as does the rest of the submarine. Many components internal to the reactor compartment are stainless steel, or are clad with stainless steel. In other submarines, a nickel-based alloy is used to clad some reactor compartment components and as a special material in construction of other components such as piping.

Table 4-5 presents typical radioactivity levels for the principal radionuclides that can be found in cruiser, Los Angeles class, and Ohio class reactor plants one year after final reactor shutdown (USN 1996).

Table 4-5. Typical Radioactivity Levels (Ci) in Cruiser, Los Angeles Class, and Ohio Class Reactor Plants One Year after Final Shutdown

| Radionuclide | Reactor Plant | | | | |
|----------------------|---------------|-----------|------------|------------|------------|
| | Type #1 | Type #2 | Type #3 | Type #4 | Type #5 |
| Te-125m | 5.0e-10 | 7.8e-5 | 8.6e+2 | 8.2e+2 | <1e-6 |
| Zr-95/ Nb-95 | 1.7/5.1e-2 | 4.4/11e-3 | 2.3/4.9e+3 | 2.2/4.7e+3 | 3.8/8.2e-3 |
| Co-58 | 1.7e+3 | 4.9e+2 | 8.4e+2 | 8.0e+2 | 1.2e+2 |
| Ta-182 | 1.2e+2 | 9.6e+1 | 1.0e+3 | 1.0e+3 | 8.2e+0 |
| Sn-119m | 4.2e-9 | 4.1e-4 | 6.8e+3 | 6.5e+3 | <1e-3 |
| Fe-55 | 6.7e+3 | 1.9e+3 | 8.8e+3 | 1.8e+4 | 4.0e+3 |
| Sb-125 | 2.3e-9 | 3.6e-4 | 4.0e+3 | 3.8e+3 | 2.0e-1 |
| Co-60 | 1.2e+4 | 3.2e+3 | 1.0e+4 | 1.0e+4 | 3.6e+3 |
| Ni-63 | 2.9e+4 | 1.5e+4 | 1.9e+4 | 3.8e+4 | 7.8e+3 |
| Total for All Listed | 5.0e+4 | 2.1e+4 | 5.9e+4 | 8.6e+4 | 1.8e+4 |

The reactor types in Table 4-4 were not associated with specific classes of ships in USN 1996, but it was noted that 60 percent of the reactors were Type #1, 20 percent were Type #2, 14 percent were Type #3, 4 percent were Type #4, and 2 percent were Type #5. Based on the number of ships commissioned, it is likely that Type #1 reactors are for Los Angeles class submarines, Type #2 reactors are for Ohio class submarines, and the remaining types are for cruisers.

4.6 Depleted Uranium Armaments

The U.S. Army uses DU for armor-piercing projectiles and for tank armor in the M1A1 Abrams main battle tank. Production of the M1A1 began in 1985, and 4,796 tanks were built for the U.S. Army and 221 for the U.S. Marines (<http://www.army-technology.com/projects/abrams/>). The “heavy armor” version of the M1A1 Abrams main battle tank uses steel-encased DU for armor. Eventually all of the M1A1 tanks will be upgraded with DU armor (<http://www.fas.org/dod-101/sys/land/m1.htm>). The M1A1 is equipped with a 120-mm M256 smooth bore cannon. One of the types of ammunition used with this gun is the M829 APFSDS-T round with a depleted uranium penetrator. DU rounds are fired only in combat (e.g., the Gulf War) or for testing purposes but not for training (Graham 2001). Firing of DU rounds from the 120 mm gun can produce very low levels of surface contamination inside the gun barrel. However, after firing a couple of rounds of regular ammunition, the contamination is removed. Damaged armor is removed from the tanks and shipped to the Nevada Test Site for disposal since design details are classified. If portions of the tank structure become damaged and consequently contaminated, the contaminated area can be cut out and disposed of as low level waste.

U.S. tanks damaged by uranium penetrators during the Gulf War were refurbished at Chem-Nuclear Systems, L.L.C. facilities in South Carolina (Porter 2001). Damaged sections of the tank bodies were cut out and disposed of as LLW. The tank interiors were decontaminated by wiping.

Guns on armored personnel carriers also use DU rounds (Cooper 2001).

The U.S. Navy has dropped the use of DU rounds from its arsenal but the Air Force continues to use DU rounds for guns in the A-10 Thunderbolt, “its top tank killer” (Cooper 2001). (The A-10 is equipped with a 30 mm GAU-8/A seven barrel Gatling gun.) When the A-10 is replaced by the Joint Strike Fighter, guns firing DU rounds will not be incorporated. The quantities of DU munitions used in recent conflicts is as follows:

| <u>Yugoslavia (1999)</u> | <u>Bosnia (1994, 1995)</u> | <u>Gulf War (1991)</u> |
|--------------------------|----------------------------|------------------------|
| Rounds - 31,000 | Rounds - 10,000 | Rounds - N.A.* |
| Tons - 9 | Tons - 3 | Tons - 320 |

* U.S. Army fired 9,552 DU tank rounds weighing 50 tons.

4.7 DOD Summary

The total number of NRC licenses or permits issued under NRC Master Materials Licenses and the number that do not involve sealed sources are summarized below:

| <u>Organization</u> | <u>Total Licenses/Permits</u> | <u>Licenses/Permits Not Involving Sealed Sources</u> |
|---------------------|-------------------------------|--|
| U.S. Navy | 139 | 55 |
| U.S. Army | 96 | 61 |
| U.S. Air Force | 376 | 41 |

Low-level wastes annually generated by the DOD facilities have been 110,000 to 120,000 ft³ per year for the past two years, with most of this waste from cleanup rather than from operations. As a group, these DOD facilities appear to raise no unique inventory issues. The operations and inventories are adequately described as part of the general materials licensee community in Chapter 2, Section 2.5.

Substantial quantities of a variety of metals are being recycled under the Nuclear Powered Ship and Submarine Recycling Program from U.S. Navy facilities not licensed by NRC. This recycling occurs after the reactor compartments are removed from the vessels and shipped to the Hanford Site for disposal.

The Army (and the Marines) have a large number of main battle tanks that use DU armor and fire DU rounds from their 120 mm guns. Any contaminated metal generated to date has been cut out of the tanks and disposed of as LLW.

If the NRC were to promulgate any new regulations relating to the clearance of solid materials from regulatory control, and the U.S. Navy and the U.S. Army adopted and applied these regulations to systems not licensed by the NRC, regulations that effectively preclude recycle into normal commercial channels could have a significant impact on how the military handles materials from ships and tanks. Setting a release criterion of "zero above background," prohibiting release of material that had been in an area where radioactive material was used or stored, or restricting release to only certain authorized uses could severely limit disposal options for these weapons systems. The extent to which other release options (such as doses limits of 1, 10, or 100 $\mu\text{Sv/a}$) might affect these agencies is not currently predictable since we have not located information on current surveying practices and levels of acceptable contamination.

5.0 GENERATORS OF TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS

This chapter discusses those unlicensed commercial industries using or processing materials which contain naturally occurring radioactivity (NORM) and which, because of their operations, create higher concentrations of radioactivity than that associated with an undisturbed natural setting. Radioactive species associated with NORM are typically uranium and thorium and their decay products. Seven industry sectors are examined, but sufficient data were found in the literature to estimate the kinds and quantities of materials and associated levels of radioactivity from only the petroleum industry.

It is estimated that the oil and gas industry generates about 130,000 tons per year of scrap steel with elevated NORM levels from operations such as well workovers, routine replacement of pipe and tubing, and salvage of abandoned wells. Scale, which builds up on the interior surfaces of oil field tubulars, is estimated to contain an average of 174 Bq of Ra-226 per kilogram of steel (4.7 pCi/g). Radioactivity levels in tanks and vessels are two orders of magnitude lower. Gas lines with TENORM are estimated to contain about 703 Bq of Pb-210 per kilogram of steel (19 pCi/g).

Chapter 5 provides information on the inventories of potentially clearable materials from industries that handle or generate technologically enhanced, naturally occurring radioactive material (TENORM). This section presents a characterization of industrial sectors that handle or process TENORM and are believed to generate contaminated scrap metals. These sectors include:

- Petroleum production (Section 5.1)
- Uranium mining (Section 5.2)
- Phosphate and phosphate fertilizers (Section 5.3)
- Coal ash from coal combustion (Section 5.4)
- Drinking water treatment (Section 5.5)
- Metal mining and processing (Section 5.6)
- Geothermal energy production (Section 5.7)

The inclusion of these industrial sectors does not imply that they are the only ones with the potential of generating TENORM-contaminated scrap metals. Other industrial sectors (e.g., paper pulp) are believed to handle or process TENORM, which could result in the generation of contaminated scrap metals. However, there is insufficient information to evaluate these sectors.

TENORM-contaminated equipment and scrap metals may be generated when handling or processing mineral and metallic ores or performing industrial processes using feedstocks

containing natural radioactivity. Depending on the process, the radioactivity present in initial material or feedstock can become concentrated, thereby resulting in radionuclide contamination levels that may be orders of magnitude higher than those of the parent material. Depending on industry sectors, the management of contaminated scrap metals relies on the sale of equipment for salvage, recycling, or disposal as TENORM waste. For example, an informal telephone survey of scrap metal dealers located in the Southwest has indicated that some types of scrap metals that are being generated by the oil and gas industry have more value for making other products than for recycling. Pipes (known as tubulars in the trade) are being used for making ranch fences, presumably under exemptions from State regulations. In other instances, the properties of scrap metals may determine how they should be managed, e.g., recycling versus disposal. For example, some equipment is internally lined with PVC, rubber, or lead liners, which precludes recycling at a steel mill unless the liners are first removed. There is much uncertainty about the rate at which scrap metals are being generated and whether generation rates reflect normal life-cycles of plant equipment, periodic maintenance dictated by operational requirements, or competitive market forces mandating that plant equipment and facilities be periodically upgraded to keep up with industry practices or standards. The disposition of scrap metals may be managed by service industries contracted to operate and maintain process equipment, as opposed to being performed by plant owners/operators, or directly through scrap metal dealers. In either case, facility operators have to determine whether to discard or refurbish and reuse equipment based on cost considerations. If equipment were to be sold as scrap, the operator would need to determine whether the scrap meets recycling industry specifications for sizing and dimensions, bulk density, cleanliness (rust, sediment, scale, oils, grease, paint coatings, etc.), residual alloying elements (e.g., Ni, Cr, Mo, or Mn), and impurities (e.g., Pb, P, S, or Si). The major radionuclides associated with TENORM include U-238, U-234, Th-230, Ra-226, Rn-222, Pb-210, Po-210 for the U-series; and Th-232, Ra-228, Ac-228, Th-228, and Ra-224 for the Th-series.

Estimating inventories of clearable material is impossible for all industry sectors except petroleum production due to the lack of relevant information. For seven out of the eight industry sectors, there is no information that describes the volumes of potentially reusable metals/materials and their associated radioactivity. Even for the one industry that has relevant information (petroleum production), it is difficult to determine source volumes and radioactivity levels making the inventory estimates presented in Section 5.1 highly uncertain.

5.1 Petroleum Industry

In North America, petroleum is extracted from 34 geologic provinces, including Alaska. Crude oil and gas are brought to the surface through production piping, known as tubulars. At the wellhead, petroleum emerges as an emulsion, with varying ratios of oil, water, and dissolved gases. In the early life of the well, most of the production stream is a mixture of crude oil and/or gas. As the reservoir ages and becomes depleted, the amounts of produced water increase with oil being present as suspended colloids or droplets. Depending upon the age of the field, secondary and tertiary recovery methods are used to enhance the recovery of any remaining oil by reducing the viscosity of the oil or solubilizing the oil/water mixture for improved production rates. Thermal processes are also being used, including steam, hot water, or in situ combustion (Pennwell 1997).

Once at the surface, the production stream passes through a series of unit operations to separate oil, gas, and water. Most of the solids in the original fluid stream are removed in the separator. The gaseous phase is sent to a gas dehydrator where any remaining moisture is removed. Then the gas is sent to flow lines conveying it to gas treating and processing facilities or to branches of a larger gathering system. From the separator, the liquid phase is further processed using heater/treaters to separate oil from produced water and sludge. Produced water from separators and heater/treaters is pumped to storage pits or tanks and used for injection through recovery wells, discharged into coastal waters, or pumped into evaporation ponds. From heater/treaters, the oil is sent to sediment and storage tanks, where remaining sediments and water are separated. From these tanks, the oil is then pumped into distribution pipelines or loaded on barges and trucks and sent to refineries. For gas wells, the gas is collected from flow or field gathering lines which are connected to gas treating and processing facilities. From such facilities, gas is sent out via transmission and distribution pipelines. The total length of the U.S. gas pipeline system is estimated to be 1.257 million miles, including 46,100 miles of field gathering lines at the point of production, 256,500 miles of transmission pipeline to major regional and metropolitan centers, and 955,300 miles of distribution pipelines to home, business, and industrial sites (AGA 1997).

5.1.1 Radioactivity Levels

5.1.1.1 Origin of Radioactivity

The radioactivity associated with petroleum extraction and production is due to the presence of primordial radionuclides present in geologic formations from which petroleum is withdrawn. The radioactivity is associated with uranium-238 (U-238) and thorium-232 (Th-232), including their respective decay products. Oil and gas extraction always involves large amounts of produced water. The amount of produced water varies depending on the age of the well and withdrawal rates, with older wells generating more produced water.

The movement of radioactivity from the geologic formation to produced water is related to several factors. Some of the important factors include mineral properties of the geologic formation, concentrations of U-238 and Th-232 in the formation, and chemical properties of produced water. Conditions that enhance the movement of radioactivity into produced water include minimal grain characterized by large surface area-to-volume ratios, porous and well connected minerals, U and Th atoms located on grain surfaces, well water-saturated pore spaces, and variation in the salinity, pH, and oxidation/reduction potential of formation water.

Uranium and thorium are not readily soluble in formation water and produced water. Uranium and radium have opposite solubilities in sulfate- and chloride-bearing water. Sulfate leaching will remove uranium, while chloride leaching will preferentially remove radium. The chemical properties of formation water determine whether radium dissolution or precipitation will occur, given that radium is present in formation water as a result of recoils, which separate radium from the host mineral during alpha decay (Fisher 1995). This process is generally assumed to be responsible for most of the presence of radium in formation and produced water. Finally, different extraction methods (such as use of steam or chemicals) are believed to foster changes in water chemistry, temperature, pressure, which in turn may change radium solubility.

Total radium (Ra-226 and Ra-228) activity in produced water is reported to vary, with concentrations on the order of 1,600 and 1,500 pCi/L, respectively (Snively 1989). Fisher (1995) reports that Ra-226 concentrations in produced water ranged from 0.1 to 5,150 pCi/L, with 95 percent of the results falling within a range of 2.0 to 2,290 pCi/L, and 41 percent being less than 100 pCi/L. The results also showed variations by geological region, e.g., 140 pCi/L in South Central Texas and 958 pCi/L in West Texas. A Michigan Department of Public Health

and Natural Resources study reported Ra-226 concentrations ranging from 100 pCi/L to as high as 2,700 pCi/L (MDPH 1991), with still higher concentrations noted in Antrim shale (9,000 pCi/L for Ra-226). In general, Ra-228 concentrations were found to be much lower, ranging from 40 to 900 pCi/L. White (1992) reports produced water radioactivity levels of 1,620 pCi/L for Ra-226 and 1,507 pCi/L for Ra-228. Meinhold et al. (1993) reports that radium in produced water discharged from Louisiana offshore platforms was as high as 584 pCi/L for Ra-226 and 586 pCi/L for Ra-228.

These studies reveal inconsistent ratios in Ra-226 and Ra-228 concentrations in produced water, since the ratio depends on the presence of U and Th in the geological formation, properties of both geologic formation, and changes in formation induced by the type of oil and gas extraction method. Ratios of Ra-228/Ra-226 have been noted to vary from 0.1 to 2.3, in produced water with conditions enhancing the solubility of radium (Snively 1989, Meinhold 1993, Fisher 1995). Armbrust and Kuroda (1956) reported Ra-228/Ra-226 ratios ranging from 0.25 to 75, based on the analyses of four petroleum brine samples.

5.1.1.2 Accumulation of Radioactivity in Process Equipment

As with any system that circulates water, scale is usually found in piping and process components. The same applies to the equipment used to extract oil and gas, including oil flow lines, water lines, injection and production well tubing, manifold piping and small diameter valves, meters, screens, and filters (API 1989; RAE 1993, RAE 1988). When present, scale thicknesses can vary from a few millimeters to tens of centimeters (Cowan and Weintritt 1976, Shuler et al. 1995, Fisher 1995, McArthur 1988). Scale thicknesses were reported to vary from 0.2 cm to 1.08 cm, averaging 0.34 ± 0.20 cm for 20 samples taken in Northern Texas (Fisher 1995). Shuler et al. reported scale thicknesses varying from 0.37 to 1.35 cm, with an average of 0.89 ± 0.39 cm (Shuler et al. 1995).

The presence of radioactivity is related to the distance from the wellhead and mixing of different produced waters from different production zones, with the highest concentrations being generally associated with equipment located nearest to the well. The buildup of scale is due to pressure drops, residence time, and flow separation. Because the chemistry of radium is similar to that of barium, the presence of radium in scale is associated with the co-precipitation of barium sulfate (Ba(Ra)SO_4), calcium sulfate (Ca(Ra)SO_4), and calcium carbonate (Ca(Ra)CO_3) (Vetter 1975). The concentration of Ra-226 in scale has been found to be proportional to the presence of barium

and salinity of produced water (Fisher 1995). Older wells typically produce much more water and, therefore, bring more dissolved radium to the surface, which yields more favorable conditions for further accumulation of radium in scale (API 1995). Ra-226 is generally present in scale in higher concentrations than Ra-228. The nominal activity appears to be about three times higher for Ra-226 than Ra-228 (RAE 1988). Fisher and Hammond (1994) report that the ratio of Ra-226 to Ra-228 in freshly precipitated scale varies from 0.4 to 1.2, with ratios ranging from 1.8 to 15 and with an average of 4.4 ± 3.0 , depending upon the age of the scale.

Table 5-1 presents a summary of data illustrating the variability of radium radioactivity levels in scale, sludge, and other types of samples. The data indicate that Ra-226 concentrations vary from levels similar to those found in natural soils to as high as 723,000 pCi/g. However, there is a cluster of data that suggests a narrower range, from 10 to 10,000 pCi/g. Similar variability can be noted for Ra-228 and Th-228.

Radioactivity levels in crude oil have been found to be very low. For example, the uranium concentration in 24 domestic crude oil samples was noted to range from 0.00004 to 0.013 ppm, with an average of 0.00186 ppm (SC&A 1995). The average corresponds to 0.00132 pCi/g, assuming a specific activity of 7.1×10^{-7} Ci/g for natural uranium. Accordingly, this section does not address oil and gas distribution systems beyond production fields.

Sludge deposits in production equipment are generally in the form of oily and loose material, with origins similar to that of scale. Sludge contains water, scale, sediments, rust, solids, and various elements at trace levels, including Se, Co, Ni, Cu, Ga, Zn, As, Y, Zr, Nb, Mo, Sn, Ta, W, Tl, and Pb (Fisher and Hammond 1994). Sludge with low oil content is similar to soil in appearance and consistency. Oily sludge must be disposed of in accordance with State and local regulations because of the presence of petroleum products.

Table 5-1. Radioactivity Levels Reported in Various
Petroleum Process and Equipment Samples

| Material/Origin | Ra-226 - pCi/g* | Ra-228 - pCi/g | Th-228 - pCi/g |
|---|---|--|--------------------|
| Scale, Tatarsan oil fields(a) | <9,000 | no data | no data |
| Scale/Precipitates(b) Mean: Median: Max: | 324 2,400 27,000 | 1,917 154 9,720 | 891 70 5,400 |
| Produced sands, Gulf of Mexico (c) 34 samples: 17 samples: 17 samples: | 17 - 150 >30 <30 | no data | no data |
| 110 produced sands samples (c), with 5%: 8%: 37%: 50%: | 1 - 350 ≥90 60<90 30<60 <30 | no data | no data |
| Sludge, Louisiana oil fields(d), range: | 1,000 - 22,220, as total radium | no data | no data |
| Scale removed from equipment (d): Downhole assay.: Downhole pump: Tubing: Wellheads: Baffler plates: | as total radium 27 - 6,027 mean: 1,351 14 - 27,243, mean: 7,729 27 - 9,729, mean: 1,459 22 - 3,378, mean: 783 81 - 1,486, mean: 703 | no data | no data |
| Pipe scale, Michigan study(e) Tank sediments (e) | 600±10 1,540±40 1,600±50 204±4 1,470±20 | 41±2 100±10 120±10 7.6±0.9 490±7 | no data |
| Scale, East Texas oil field(f) | 7,800 | 3,000 | no data |
| Scale, Southern Louisiana oil field(g) | 3,680 | 2,130 | 2,270 |
| Scale, Texas (h) | 397 - 2,762 mean: 1,669±865 | 512 - 4,064 mean: 2,596±1,249 | no data |

| Material/Origin | Ra-226 - pCi/g* | Ra-228 - pCi/g | Th-228 - pCi/g |
|---------------------------------|--|---------------------------------------|----------------|
| Oil production vessel solids(i) | 7.1 - 723,200 mean: 62,201±176,017 | 1.5 - 49,620 mean: 8,867±16,965 | no data |
| Scale, California(j) | 0.26 - 1,121 mean: 204±311 | 0.22 - 1,182 mean: 188±331 | no data |
| Scale, 5 samples, Italy (k) | 30 - 2,890 mean: 855±1,224 | no data | no data |
| Scale, 1 sample, North Sea (k) | 780±156 | | |
| Scale, 3 samples, Tunisia (k) | 31 - 1,189 mean: 428±659 | | |
| Scale, 2 samples, Congo (k) | 97±20 and 151±30 mean: 124±38 | | |
| Sludge, 3 samples, Tunisia (k) | 66 - 453 mean: 229±200 | | |

* 1 pCi/g = 0.037 Bq/g

Table modified from EPA 1997b.

a Diyashev et al. 1994.

b Kolb and Wojcik 1985.

c Hardy and Kahtib 1996.

d Reed et al. 1991. Total radium, includes Ra-228, Ra-226, and Ra-224. Results include data for scale removed from equipment located in Scotland.

e MDPH 1991.

f Hayden and Kramer 1995.

g Dehmel et al. 1992.

h Fisher 1995 and Rood and Kendrick 1996.

i Fisher and Hammond 1994.

j CDHS 1996.

k Testa et al. 1992.

The radioactivity in gas treating and processing plants is different than that found in oil extraction and production systems (Gray 1991, Grice 1991). The residues are assumed to be present as gummy deposits, with a density similar to that of oil (0.89 g/cm³) (NBS 1969, Gray 1991, Grice 1991). In gas processing plants, the radioactivity is due to radon (Rn-222), which originates from underground sources and becomes mixed with the gas being extracted. Radon concentrations vary from non-detectable levels to about 1,450 pCi/L (EPA 1973, 1977). The average radon level from eight gas-producing regions located in the United States is reported to be about 40 pCi/L, ranging from about 1 to 1,460 pCi/L (UNS 1982). Radon concentrations have also been noted to increase as gas supplies near depletion. Radon, with a boiling point of

-61.7°C (CRC 1995a), between that of ethane (-88.6°C) and propane (-42.1°C) (CRC 1995a), usually follows ethane during processing by liquefaction.

Since radon decays with a 3.8-day half-life, the only significant long-term source of radioactivity is due to Pb-210 and Po-210. Pb-210 has a half-life of 22.3 years and decays to Po-210, via Bi-222, by emitting two weak beta particles and one weak gamma ray. Bi-210 has a half-life of 5 days and decays by emitting an energetic beta particle. Po-210, with a half-life of 138.4 days, decays by emitting an alpha particle. Consequently, these radionuclides do not have radiation emissions energetic enough to pass through the steel walls of most processing equipment, and their presence can be assessed only by taking internal measurements.

Radon decay products plate out and accumulate on interior surfaces of gas plant equipment. Equipment with elevated radiation levels typically includes compressors, cryogenic units, reflux pumps, fractionation towers and columns, propane tanks, and piping handling liquefied petroleum gases. During maintenance, any remaining radon that has not yet decayed is vented and dispersed into the atmosphere when the equipment is opened for servicing. Consequently, the levels of radon decay products in gas production equipment depend on how long the gas has remained in the system and the degree of equilibrium depending on initial radon levels.

Internal Pb-210 and Po-210 radioactivity levels inside gas plant equipment at facilities located in Western Canada are summarized in Table 5-2. Levels of Pb-210 and Po-210 vary, ranging from nondetectable levels to 1,350 pCi/g (Drummond et al. 1990). However, activity levels have been reported to be much higher in other instances, up to 10^5 pCi/g (Scott 1997). Samples taken on surfaces of pump impellers and casings have revealed relatively low levels of removable contamination, ranging from 14 to 57 pCi/cm² for Pb-210 and 5.4 to 43 pCi/cm² for Po-210 (Drummond et al. 1990).

Table 5-2. Radioactivity Levels in Gas Plant System Components^(a)

| System | Pb-210 (pCi/g) | Po-210 (pCi/g) |
|------------------------------|----------------|----------------|
| Propane treater vessel | 229±14 | 219±5.4 |
| High pressure flash tank | 10±1.4 | 7.8±1.1 |
| Inlet gas exchanger/scrubber | 2.7 | 2.7 |
| Vessels (typical) | <5.4 | 0.54 - 7.8 |
| Drip samples (6) | 27 - 1,350 | ----- |
| Drip samples (5) | 1.4 - 54 | <0.14 - <5.4 |

a Adapted from EPA 1997a - data extracted from Drummond 1990, Tables 2 and 3

5.1.1.3 External Radiation Levels from Contaminated Equipment

The results of radiation survey measurements conducted by Otto are the most consistent set of data available to date characterizing radiation levels in oil and gas equipment (API 1989).

The report describes the results of 36,890 measurements taken in 20 States and on two offshore facilities. The data reveal wide variations in radiation exposure rates. The variations are due to varying radionuclide concentrations, different ratios of Ra-226 and Ra-228, uneven scale and sludge deposits, self-shielding from steel walls of the equipment, and different equipment and radiation detector configurations encountered during the survey. The author notes that the data may be biased, as the survey method was not always capable of detecting the presence of NORM. Most of the measurements were made at sites already suspected of having elevated radioactivity levels, as opposed to using a random approach in selecting facilities. In addition, the measurements were made to determine the presence of NORM, as opposed to determine true exposure rates. Finally, the author points out that the number of measurements made within oil or gas fields was not proportional to their productive capacity.

The data indicate that about 64 percent of the gas equipment and 57 percent of the oil production equipment contained scale with radiation levels that were not distinguishable from background, meaning that about 30 to 40 percent of the equipment is believed to contain NORM at elevated levels. The geographic areas with the highest equipment readings include the entire Gulf Coast, Northeast Texas, Southeast Illinois, and a few counties in Southern Kansas. The Eastern Gulf Coast area from Mississippi to the Florida Panhandle showed consistently higher radiation exposure rates.

For oil production equipment, the median exposure levels range from 20 to 40 $\mu\text{R/h}$ (about 2 to 4 times background). In gas processing equipment, exposure rates range from 30 to 80 $\mu\text{R/h}$. At the 99th percentile, the exposure rates were estimated to be 500 and 530 $\mu\text{R/h}$ for oil and gas equipment, respectively (Otto 1990). Some measurements revealed exposure rates ranging from 1,000 to 4,000 $\mu\text{R/h}$ for gas production equipment, including pumps (reflux and others), product lines, and propane tanks. For oil production equipment, elevated exposure rates were observed in flow lines, water lines, and injection wells.

The results presented in the Otto report are comparable to those obtained in other studies conducted in Kentucky, California, Michigan, Louisiana, and Florida (Ashland 1993; Bailey 1995; CDHS 1996; EPF 1987; ERG 1996; Gray 1991; Greer and Landress 1995; Miller 1987,

1988, MDPH 1991; NAHCM 1990; Rajitar et al. 1994; Rajitar 1995; Smith 1987; Tiger 1991; UKOOAL 1985; Volpe 1994).

5.1.2 Quantities of Contaminated Scrap Materials

Most of the contaminated scale is contained in oil and gas production equipment. Contaminated equipment may be decontaminated and reused, disposed of, or sold as scrap. Decontamination involves the removal of scale and sludge using several methods. The selection of any specific method depends on the type of equipment, amounts of scale or sludge present, whether the scale/sludge is fixed or loosely distributed, removal efficiency, and cost. The removal of scale and sludge varies, with reduction factors ranging from 2 to 50, averaging 21 ± 13 . The reduction factors are based on radiation exposure rate measurements taken before and after cleaning (Table 5-3). The waste-to-component volume ratios also varied from 0.003 to 0.816, with an average of 0.097 ± 0.175 . The data reflect the use of manual, mechanical, and high-pressure water cleaning methods on vessels and tanks only. In other instances, waste volume reductions on the order of 80 percent have been reported for scale (Smith et al. 1995) and 8-to-1 for waste saturated with water and hydrocarbons (Welther and Burton 1994).

Because the data presented in Table 5-3 do not include equipment weight, it is difficult to assess the tonnage or bulk density of the equipment. In most instances, the equipment weight and type of steel are given on data plates affixed to the equipment or included in specifications describing the equipment. Lacking specific information, the bulk density is assumed to be 2.6 g/cm^3 (RAE 1993). It should be noted that the bulk density of scrap metals readied for steel mills is seldom less than 1.2 g/cm^3 (AMM 1999). For heavier grades of scrap metal, such as that generated by the oil and gas industry, the total tonnage and bulk density are determined at the time of shipment, depending on whether the material is prepared by the generator or scrap dealer (AMM 1999).

There are no definitive estimates of the amounts of scrap metal that the oil and gas industry generate annually. The estimates that have been made vary significantly, are highly uncertain, and in many instances, are not comparable.

Table 5-3. Equipment Decontamination Waste Volume and Reduction Factor^(a)

| Component | Component Size | | Component | Waste | Volume Ratio | Exposure Rate ($\mu\text{R/h}$) | | Reduction Factor |
|--------------|----------------|-------------|------------------------|------------------------|--------------|-----------------------------------|-------|------------------|
| | Width (ft) | Length (ft) | Vol. (ft^3) | Vol. (ft^3) | Waste/Cmpnt | Before | After | Before/After |
| Separator | 1.7 | 10.0 | 21.8 | 2.10 | 0.096 | 200.0 | 20.0 | 10.0 |
| Separator | 1.7 | 10.0 | 21.8 | 0.10 | 0.005 | 20.0 | 10.0 | 2.0 |
| Separator | 1.7 | 10.0 | 21.8 | 2.10 | 0.096 | 900.0 | 20.0 | 45.0 |
| Heater | 3.8 | 11.0 | 126.9 | 4.21 | 0.033 | 200.0 | 10.0 | 20.0 |
| Separator | 2.0 | 10.0 | 31.4 | 0.10 | 0.003 | 100.0 | 20.0 | 5.0 |
| Heater | 3.0 | 10.0 | 70.7 | 2.10 | 0.030 | 240.0 | 20.0 | 12.0 |
| Separator | 2.5 | 10.0 | 49.1 | 4.21 | 0.086 | 210.0 | 10.0 | 21.0 |
| Heater | 4.0 | 10.0 | 125.7 | 2.10 | 0.017 | 120.0 | 8.0 | 15.0 |
| Separator | 2.5 | 10.0 | 49.1 | 2.10 | 0.043 | 280.0 | 8.0 | 35.0 |
| Scrubber | 2.5 | 10.0 | 49.1 | 2.10 | 0.043 | 200.0 | 10.0 | 20.0 |
| Separator | 2.5 | 10.0 | 49.1 | 4.21 | 0.086 | 300.0 | 8.0 | 37.5 |
| Separator | 2.0 | 10.0 | 31.4 | 4.21 | 0.134 | 500.0 | 10.0 | 50.0 |
| Separator | 2.0 | 8.0 | 25.1 | 6.31 | 0.251 | 300.0 | 10.0 | 30.0 |
| Separator | 2.5 | 10.0 | 49.1 | 4.21 | 0.086 | 300.0 | 14.0 | 21.4 |
| Separator | 1.0 | 5.0 | 3.9 | 0.02 | 0.005 | 70.0 | 8.0 | 8.8 |
| Separator | 1.0 | 5.0 | 3.9 | 0.02 | 0.005 | 60.0 | 8.0 | 7.5 |
| FW-Knckout | 3.5 | 15.0 | 144.3 | 117.80 | 0.816 | 300.0 | 20.0 | 15.0 |
| Separator | 2.5 | 10.0 | 49.1 | 4.21 | 0.086 | 400.0 | 18.0 | 22.2 |
| Separator | 3.0 | 9.9 | 70.1 | 2.80 | 0.040 | 300.0 | 14.0 | 21.4 |
| H-Treater | 6.0 | 30.0 | 848.2 | 42.07 | 0.050 | 200.0 | 15.0 | 13.3 |
| 210-bbl Tank | 8 | 23.5 | 1179.0 | 25.24 | 0.021 | 500.0 | 20.0 | 25.0 |
| Min.: | 1.0 | 5.0 | 3.9 | 0.02 | 0.003 | 20 | 8 | 2 |
| Max.: | 8.0 | 30 | 1181.2 | 117.80 | 0.816 | 900 | 20 | 50 |
| Average: | 2.8 | 11.3 | 144.0 | 11.06 | 0.097 | 271 | 13 | 21 |
| Std. Dev. | 1.6 | 5.6 | 296.7 | 26.36 | 0.175 | 193 | 5 | 13 |

a Adapted from EPA 1997a - Data from survey reports (Tiger 1991). Component volumes assume a right cylinder configuration with the width being equivalent to the diameter. Waste volumes are as reported, with residual removed from cleaning equipment (29.4 ft^3), apportioned to each component as a function of collected waste volume. Total overall component volume is $3,023 \text{ ft}^3$, and the total waste volume is 232.3 ft^3 .

Complications arise because service companies are often used to conduct characterizations or remediation, with some of the information about waste volumes and radiological properties being held as confidential. Even for data submitted to State regulatory agencies, the reports prepared by service companies generally combine all information into a few categories, e.g., total waste volumes and total activity levels by job site. As a result, such reports do not give the resolution necessary to separate data by waste streams, equipment, and radionuclide concentrations.

Finally, the industry is conducting cleanups and updating operating practices, and these efforts and new measures are expected to lower future waste volumes. However, these new practices are not expected to make much difference in current inventories of stockpiled waste, consisting of scrap metals in addition to contaminated soils, sludge, and sediments.

Table 5-4 summarizes various estimates of waste generated by the oil and gas industry. As can be noted, annual waste volume estimates vary widely from 3,000 to 600,000 m³ for all waste streams. Some examples of the uncertainties causing this wide variability in volume estimates are described below.

One estimate often quoted cites an annual generation rate of about 172,800 metric tons (t) (Blunt and Smith 1995, Smith et al. 1996). This estimate is based on limited information, extrapolates to industrywide practices using isolated practices and data, and incorporates large uncertainties.

Table 5-4. Estimates of Waste Generation Rates from Various Petroleum Industry Studies

| Waste/Material | Amount | Reference |
|--|---|---|
| Scale/Sludge/Other, 1993 data | 3,000 - 30,000 m ³ /y | API 1996 |
| Cumulative inventory, all wastes, based on 1993 data | 2.1 - 3.4 million m ³ | API 1996 |
| Scale/Sludge, based on 1992 data | 45,300 m ³ /yr | Smith et al. 1995 |
| Scale/Sludge, based on 1990 data | 600,000 m ³ /yr | Spaite 1992 |
| Production equipment | 172,800 t/yr | Blunt and Smith 1995 & Smith et al. 1996 |
| Surface equipment, tubulars, injection pipes, and casings. Excludes gas gathering lines. | 100,000 t/yr (30,000 - 300,000 t/yr) | EPA 1997b |

Another estimate (API 1996) presents waste volume estimates for all waste streams, thereby censoring out useful information. The API study acknowledges the limitations of its own assessment by noting that waste volumes might be underestimated by a factor of at least two and possibly as high as ten. As a result, the API applied a factor of 10 to its waste volume estimates to account for various sources of uncertainty.

In its revised NORM Waste Report, the EPA provides estimates for scrap metal categories in several groups (EPA 1997b). The categories including tubulars, casings, injection piping, and surface equipment originating from different activities are summarized in Table 5-5. Some of the

most significant uncertainties in the EPA's estimates are derived from the assumptions that were made. All wells were assumed to be a mile deep, and contained 24 t of tubulars and 103 t of casings, for a total of 127 t. The EPA report assumed that 30 percent of the wells contain elevated NORM levels. Except for well workovers, all metal scrap was assumed to be generated yearly, based on a 30-year material recovery cycle. For well workovers, metal scrap was assumed to be generated annually as part of routine maintenance involving nearly 1,400 production wells.

The basis for the oil industry estimates is as follows (EPA 1997b):

- Well Closures: 13,900 wells closed annually, 127 t of tubulars/casing per 5,200 ft well, 30 percent of wells contaminated with NORM, 30 years to complete well field restoration
- Routine Production Well Workovers: 135,000 production wells in service, 24 t of tubulars replaced per workover, 30 percent of wells contaminated with NORM, 1% annual workover rate
- Injection Well Workovers and Closures: 173,000 injection wells in service, 24 t of tubulars per well, 30 percent of wells contaminated with NORM, tubulars removed over 30-year period
- Orphan Well Salvage: 2,700 wells abandoned per year (1/3 with salvageable pipe), 127 t of tubulars/casing per well, 30 percent with NORM contamination
- Surface Equipment Replacement: 12 m³ of surface equipment (tanks, separators, etc.) per 10-well facility, 87,000 facilities, 30 percent NORM contaminated, 30-year recovery recycle

For the amount of scrap metal associated with gas flow and gathering lines in Table 5-5, it was assumed that the linear density of a 4" diameter line was 22 t per mile (Kennedy 1993, WNGS 1996). As with scrap metal from oil wells, it was assumed that 30 percent of the total inventory of gas well piping (46,100 miles) was characterized by elevated NORM levels and that the corresponding length of gathering lines (13,830 miles) was replaced over a 30-year life cycle. Scrap metal from equipment beyond gas flow and gathering lines and gas treating and processing facilities were ignored since radon levels become diluted in transmission and distribution pipelines. It was assumed that as distances from gas wells increase, radon concentrations and those of radon decay products in gas decrease to levels that are very low and have insignificant impacts on the handling and disposition of scrap metals. It is also assumed that gas transmission

and distribution pipelines are less likely to be replaced than the gas lines located nearest to gas wells. The yearly amount of scrap metal considered to be contaminated is estimated at about 10,000 t. The addition of metal scrap from gas flow and gathering lines brings the total annual generation rate to about 130,000 t (Table 5-5).

In spite of the uncertainties involved in estimating quantities of NORM contaminated scrap discussed above, an uncertainty factor of ten (as used by API) seems too high. For the purposes of this study, a factor of three is assumed to bracket the range of the amounts of metal scrap based on a central estimate of 130,000 t. The range is estimated to vary from about 40,000 to 400,000 t per year.

Table 5-5. Estimates of Annual Scrap Metal Generation Rates
by the Oil and Gas Industry

| Equipment | Origin | Amount (t/yr) |
|------------------------------|----------------------------------|---|
| Tubulars/Well casing | Well closures | 20,000 |
| Tubulars | Routine well workovers | 10,000 |
| Injection piping | From well closures and workovers | 40,000 |
| Surface production equipment | Routine replacement | 20,000 |
| Tubular/Well casing | Orphan wells salvage | 30,000 |
| Gas flow and gathering lines | Routine replacement | 10,000 |
| | | Total: 130,000 Range: 40,000 - 400,000 |

Note: Except for gas flow and gathering lines, data adapted from EPA 1997b.
All estimates are rounded off. Upper and lower estimates are assumed to be a multiple of the central estimate, using a factor of three. See text for details.

5.1.3 Residual Levels of Radioactivity in Equipment Released for Recycling

There have been several attempts to develop methods for estimating the amounts of radioactivity based on external radiation survey measurements (SENES 1997, MDPH 1991, Smith 1987, LDEQ 1991, RAE 1989). Table 5-6 summarizes the data used to establish such relationships. The data reveal two relationships, one for pipes, manifolds, and valves, and another for tanks and vessels. For piping configurations, the conversion factors range from 1.9 to 56 pCi/g per $\mu\text{R/h}$, with three distinct averages of 32 ± 18 , 14 ± 10 , and $11 \text{ pCi/g per } \mu\text{R/h}$. For equipment consisting of vessels and tanks, the conversion factors range from 0.7 to 10 pCi/g per $\mu\text{R/h}$, with three averages of 1.6 ± 1.3 , 2.7 ± 1 , and $10 \text{ pCi/g per } \mu\text{R/h}$. The disparities in the data reflect differences in measurement methods, equipment-to-detector geometries, ratios of Ra-226 and Ra-228,

thicknesses of scale and sludge deposits and equipment wall, and effects of ambient background radiation on measurement levels approaching those of background. Rogers has developed a relationship that takes into account some of these complicating factors (RAE 1989). However, the expression developed for this purpose requires detailed information about the equipment and properties of the deposits, such as the thickness of the scale or sludge, equipment wall thickness, scale or sludge density, equipment diameter, and instrument calibration factors for specific configurations of equipment and radiation detector.

Table 5-6. Relationships between External Radiation Exposure Rates and Radionuclide Concentrations

| Waste/Material | Equipment | Concentration of Residue (pCi/g) | Range Factor (pCi/g per μ R/h) | Avgr. Factor (pCi/g per μ R/h) | Reference |
|---|--|----------------------------------|------------------------------------|------------------------------------|------------|
| Scale - Ra-226, 9 data points | Pipe, valve, manifold, meter, screen, filter | 34.8 - 1,986 | 3.7 - 56 | 32 ± 18 | SENES 1997 |
| Sludge - Ra-226, 6 data points | Vessel, tank, separator, heater/treater | 9.2 - 143 | 0.7 - 3.6 | 1.6 ± 1.3 | Ibid. |
| Scale - Ra-226 + 228 (assumed), 10 data points | Piping | 13 - 5,220 | 1.9 - 28.4 | 14 ± 10 | LDEQ 1991 |
| Sediments - Ra-226 + 228 (assumed), 2 data points | Vessels | 200 - 5,500 | 2.0 - 3.4 | 2.7 ± 1 | MDPH 1991 |
| Sludge - Ra-226 + 228 (assumed) | Vessels | 150 | 10 | 10 | Ibid. |
| Scale - Ra-226 + 228 (assumed) | Pipes | 150 | 11.5 | 11.5 | Ibid. |
| Scale - Ra-226 + 228 (assumed) | Pipes | 2,000 | 11.1 | 11.1 | Smith 1987 |

Given the paucity of the data, it is difficult to assign a specific conversion factor; however, for the purpose of this study, the factors developed by SENES (1997) are used since they are based on the Otto data, which included several thousand measurements (API 1989). The conversion factors are assumed to be 32 pCi/g per μ R/h for pipe-like configurations and 1.6 pCi/g per μ R/h for vessels and tanks. These conversion factors are used here to assess residual levels of radioactivity in equipment after decontamination.

For illustrative purposes, the exposure rates after decontamination presented in Table 5-3 are used to derive estimates of the levels of residual radioactivity remaining in residues present in equipment after decontamination. A review of the results suggests that the resulting residual radium concentrations are significant, assuming that the relationships and conversion factors used here are representative of actual field conditions. The implications are that equipment released under conditions determined by simple external radiation measurements may still contain possibly elevated residual amounts of Ra-226 activity, ranging from 13 to 640 pCi/g of residue, as illustrated below:

| <u>Equipment</u> | <u>Radiation Level (μR/h)</u> | <u>Conv. Factor (pCi/g per μR/h)</u> | <u>Ra-226 Conc. (pCi/g)</u> | <u>Ra-226 Conc. (Bq/g)</u> |
|------------------|--|---|---------------------------------|--------------------------------|
| Piping | Range: 8 - 20 | 32 | 260 - 640 | 9.6-24 |
| | Average: 13 | 32 | 420 | 16 |
| Vessels | Range: 8 - 20 | 1.6 | 13 - 32 | 0.48-1.2 |
| | Average: 13 | 1.6 | 21 | 0.78 |

The derived concentrations are for residues only and not for steel. The effective radium concentration in steel is derived later.

Regarding the presence of Pb-210 and Po-210 in gas processing equipment, no data are available to develop similar relationships for converting either internal surface radiation measurements or gross alpha and beta radioactivity levels to meaningful radiological units (pCi/g or pCi/100 cm²). The data presented in Table 5-2 indicate that Pb-210 and Po-210 can vary from about 1 to 1,350 pCi/g in surface layers, while other information indicates much higher concentrations (up to 10⁵ pCi/g) have been observed. Given the difficulties in making internal measurements for beta and alpha radiation, it is likely that such equipment could be recycled with elevated surface levels of radioactivity. The difficulty in assessing the presence of Pb-210 and Po-210 is that alpha and low-energy beta particles are totally attenuated by internal deposits, such as residues, condensates, etc., thereby leading to the erroneous conclusion that the equipment is free of radioactivity.

For the purpose of this study, an average concentration is derived by eliminating the highest value and all values below 10 pCi/g shown in Table 5-2, as the results vary over three orders of magnitude. The resulting average is assumed to be 80 pCi/g. The range is assumed to vary by a factor of three about the mean (from 27 to 240 pCi/g), lacking specific data. As with scale, these concentrations are for residues only and not for steel. The effective Po/Pb concentration in steel is derived later.

The above information is used to generate an estimate of the potential inventory of radioactivity contained in scrap metal. The inventory assumes that the radioactivity is present as a relatively thin layer of residue. The thickness of the layer of residues is derived by applying a factor accounting for the removal of some of the residues during cleanup. A thickness of 0.04 cm is assumed for residual scale, based on an average value of 0.89 cm for the thickness of the scale before cleanup (Shuler et al. 1995), and an average decontamination factor of 21 (see Table 5-3). Numerous State regulations require that equipment with external radiation levels above 25 $\mu\text{R/h}$ (exclusive of background) or 50 $\mu\text{R/h}$ (inclusive of background) be decontaminated before being released for any use. This approach reflects current industry practices. The density of the residual layer of material is assumed to be 2.5 g/cm^3 . For gas flow and gas gathering lines, the residue is assumed to be an oily gum-like deposit with a density similar to that of oil (0.89 g/cm^3), also present at a thickness of 0.04 cm (NBS 1969, Gray 1991, Grice 1991).

The surface area of production components, which are assumed to contain a layer of scale, was derived for an average tank or vessel and applied to the total inventory of surface equipment. Based on the data presented in Table 5-3, the nominal internal surface area of a typical tank or vessel is estimated to be 112 ft^2 or $1.0 \times 10^5 \text{ cm}^2$, assuming a gross diameter of 2.8 ft and length of 11.3 ft. This estimate does not account for additional surface area related to internal components, baffles, pipes, joints, flanges, manway covers, access plates, and welds. The overall total inventory of Ra-226 is prorated over the tonnage of steel scrap from surface equipment (20,000 t from Table 5-5), assuming a scrap bulk density of 2.6 g/cm^3 , yielding a total of 3,900 equivalent components.

A similar approach was used to derive the internal surficial area of oil and gas production piping and well casings. The length of the piping is based on an assumed well depth of 5,200 feet and specific amounts of tubular and casing pipes for each well. As noted previously, each well is assumed to contain 24 t of tubulars and 103 t of casings, for a total of 127 t. The total internal surface area of tubulars is estimated to be $2.9 \times 10^3 \text{ ft}^2$ or $2.7 \times 10^6 \text{ cm}^2$ per well, assuming an effective inner diameter of 2.16 inches. For casings, the total internal surface area is assumed to be $1.0 \times 10^4 \text{ ft}^2$ or $9.4 \times 10^6 \text{ cm}^2$ per well, assuming an inner diameter of 7.5 inches. Again, these estimates do not account for additional surface areas associated with exposed threads linking all tubulars and casings over that depth. The overall total inventory of Ra-226 is prorated by the tonnage of steel scrap per wells, taking into account the distribution of steel among tubulars, well casings, and injection piping. As shown in Table 5-5, it is assumed that well casings generate 50,000 t of scrap metal annually and tubulars from well workovers generate another 50,000 t.

For piping used as gas flow and gas gathering lines, the estimate is based on information presented earlier, which assumes a 3.5-inch internal diameter and a pipeline length of 13,830 miles. The internal surface area of the pipe is 0.929 ft² per ft (WNGS 1996). The internal surficial area is estimated to be 6.78×10^7 ft² or 6.3×10^{10} cm², which does not account for additional surface areas consisting of joints, flanges, condensate drains, and welds. The overall total inventory of radioactivity is based on the total tonnage of steel scrap and assumed ranges of Pb-210/Po-210 concentrations developed from the data presented in Table 5-2.

Table 5-7 is a summary of the key parameters used in calculating the inventory of radioactivity and resulting effective concentrations in steel using Ra-226 and Pb-210/Po-210. At this time, these radionuclides are used as indices of potential radioactivity levels; the presence of other radionuclides (precursors and/or decay products) would need to be accounted for in developing a complete inventory.

Table 5-7. Radioactivity Concentrations in Steel Scrap from the Oil and Gas Sector

| Metal//Tonnage/ Radionuclide | Residue Conc. (pCi/g) | Surface Conc. (pCi/cm ²) | Inventory (mCi) | Effective Steel Conc. (pCi/g) | Effective Steel Conc. (Bq/g) |
|---|--------------------------|---|--------------------|----------------------------------|---------------------------------|
| Piping/Tubulars 100,000 t Ra-226 | | | | | |
| Low: | 260 | 28 | 290 | 2.9 | 0.11 |
| High: | 640 | 68 | 710 | 7.1 | 0.26 |
| Average: | 420 | 44 | 470 | 4.7 | 0.17 |
| Tanks/Vessels 20,000 t Ra-226 | | | | | |
| Low: | 13 | 1.4 | 0.57 | 0.028 | 0.0010 |
| High: | 32 | 3.4 | 1.40 | 0.069 | 0.0026 |
| Average: | 21 | 2.2 | 0.90 | 0.045 | 0.0017 |
| Gas Lines 10,000 t Pb-210/Po-210 ^(a) | | | | | |
| Low: | 27 | 1.0 | 64 | 6.4 | 0.24 |
| High: | 240 | 9.1 | 570 | 57 | 2.1 |
| Average: | 80 | 3.0 | 190 | 19 | 0.70 |

a For gas flow and gas gathering lines, it is assumed that the estimated concentrations apply equally to Pb-210 or Po-210.

5.2 Uranium Mining

Uranium mines are not regulated by the NRC. Uranium mills and in-situ leaching facilities, which are regulated by the NRC or Agreement States, are discussed in Chapter 2 (Section 2.3.1). Individual States or, on Federal lands, the Bureau of Land Management, enforces mining regulations.

Uranium is mined by conventional techniques, in both open-pit and underground settings. In general, conventional mining methods produce large amounts of solid wastes. Open-pit mining typically produces larger amounts of waste rock and overburden than underground mining. Overburden and waste rock are usually stored in piles on site and used as backfill during mine and site reclamation.

For the period 1993-1999, no open-pit mines operated in the United States. Over that same period, the number of operating underground mines ranged from zero to four, with three operating in 1999 (DOE 2000a).

5.2.1 Radioactivity Levels

5.2.1.1 Origin of Radioactivity

There is little information about the radiological properties of uranium mining wastes and overburden. Typically, the literature focuses on ores, ore grades, and physical and radiological properties of mill tailings. For example, the NRC Final Generic Environmental Impact Statement on uranium milling does not address overburden material in its characterization of the industry (NRC 1980b).

Radionuclide concentrations in uranium mine waste are known to vary widely (EPA 1985, NRC 1980b). Factors that affect radionuclide concentrations in mining waste, other than the U content of the ore body itself, include the techniques used to remove the overburden and survey techniques used to define the boundaries of the body that will be mined. Radionuclide concentrations in overburden and waste rock have been reported in an EPA study characterizing 58 samples (EPA 1985). The EPA reported that 69 percent of the samples had Ra-226 concentrations greater than or equal to 5.0 pCi/g, and over 50 percent had concentrations above 20 pCi/g. In its 1983 Report to Congress, the EPA indicated that waste rock contained, on

average, concentrations of about 6 pCi/g for U-238 and about 1 pCi/g for Th-232 (EPA 1983). Other data from two Wyoming mines revealed Ra-226 concentrations in overburden ranging from 2 to 200 pCi/g, with an average of about 61 pCi/g (SMI 1996, Umetco 1996).

While the range of radium concentrations is relatively wide, the EPA has assumed a concentration of 30 pCi/g for Ra-226 and 1.0 pCi/g for Th-232 (EPA 1997b). Secular equilibrium of the U-238 decay series products through Ra-226 was also assumed, given that overburden materials are not processed for U recovery. The concentration of U-235 and its decay products are estimated to be 5 percent that of U-238, or about 1.5 pCi/g. The excavation and relocation of overburden materials from the ore body to stockpile areas are not expected to alter this equilibrium (Wogman 1979).

5.2.1.2 External Radiation Exposure Rates from Processing Equipment

A characterization of uranium mining overburden at 25 sites revealed radiation exposure rates from 20 to 110 $\mu\text{R/h}$, averaging about 40 $\mu\text{R/hr}$, including background. Exposure rates from low-grade ore material were found to be higher, ranging from 80 to nearly 1,000 $\mu\text{R/h}$, with an average of 200 $\mu\text{R/h}$. Ambient background levels ranged from 10 to 85 $\mu\text{R/hr}$, averaging about 20 $\mu\text{R/h}$.

In its 1983 Report to Congress, the EPA cited measurement results from two mines (EPA 1983). The results were reported to vary from 25 to 250 $\mu\text{R/h}$, with a mean of about 100 $\mu\text{R/h}$. A survey of the Gas Hills Mining District revealed radiation levels ranging from 5 to 80 $\mu\text{R/h}$, with an assumed average of 50 $\mu\text{R/h}$. The data characterize levels in areas that surround the restricted area where mining takes place, such as piles of sub-ores, wastes, and overburden, and pits (Umetco 1996). All results below 20 $\mu\text{R/h}$ were reported to be typical background radiation levels. Neither study provides radiation levels around ores and yellow-cake processing equipment.

5.2.2 Quantities of Contaminated Scrap Materials

The operations of mining facilities and their subsequent decontamination and decommissioning and site reclamation activities are expected to generate contaminated scrap metals and equipment. Materials expected from underground mines include excess structural materials used to support underground workings, underground loading and haulage equipment, drilling

machines, compressors, and equipment used to hoist the ore to the surface. Equipment potentially available from open-pit mining operations is typically heavy earth-moving units such as scrapers, bulldozers, ore hauling trucks, and graders. If this equipment has resale value, it will probably be decontaminated by water washing with high-pressure hoses.

Since the number of mines is limited, quantities of scrap metals and used equipment for recycle/reuse will be small. However, insufficient data are available to quantify the actual amounts.

5.3 Phosphate and Phosphate Fertilizer Production

Phosphate ores are extracted from open pit mines, with half being located in Florida and the balance located in Tennessee, Idaho, Montana, Wyoming, Utah, and North Carolina. Mines in Tennessee and Montana have not been in operation since 1994 (Cantrell 1995, Searls 1997). The production of phosphate rock peaked in 1980, when 54 million t of phosphate rock were produced (TVA 1986). Over the past decades, production has varied, sometimes decreasing from year to year (e.g., 1992 to 1993), depending on demand with recent annual production rates being around 40 million t (TVA 1986, BOM 1988, TFI 1989, TFI 1996).

Phosphate rock (or phosphorite) is an amorphous form of the mineral apatite (francolite or carbonate-fluorapatite). Phosphate ore consists equally of about one-third quartz sand, one-third clay minerals, and one-third phosphatic particles. After mining, the ore is processed by beneficiation (washing and flotation processes) to separate phosphate particles, followed by drying. The beneficiated phosphate is further processed to produce phosphoric acid or elemental phosphorus. These two products, along with other chemicals, are used to make phosphate fertilizers, detergents, animal feed, food ingredient, and phosphorus chemicals. Phosphate is mostly used for producing fertilizers, which accounts for over 90 percent of the phosphate rock production in the United States (DOI 1996).

The amount of waste generated is primarily related to the production of phosphoric acid. The process yields phosphogypsum and small amounts of hydrofluoric acid. The hydrofluoric acid is eventually turned into fluorosilicic acid and sold as a byproduct to the fertilizer production industry. The phosphogypsum is a waste byproduct and generally does not have any subsequent use. After separation from the reaction mixture, the phosphogypsum filter cake is slurried with water and pumped to waste piles, commonly referred to as phosphogypsum stacks.

Approximately 5 t of phosphogypsum is generated for each metric ton of phosphoric acid produced. About 80 to 100 percent of the Ra-226 found in phosphate rock goes with phosphogypsum, while about 70 percent of the uranium and thorium remain with phosphoric acid.

One exception is a process used in Idaho where ores are processed in large electric furnaces using carbon and silica as catalysts; thereby, bypassing the beneficiation stage. Crushed and screened phosphate rock is heated to its melting point (1,300°C). After calcining, the hot nodules are fed into electric furnaces along with silica and coke. Slag is the principal waste byproduct of elemental phosphorus and ferrophosphorus, which are used in making specialty steel, cast alloys, and paint pigments (EPA 1989). Depending on the type of plant, it requires about 11 t of mined phosphate rock to produce one ton of phosphorus by the thermal process (EPA 1984, EPA 1989 and 1989a). Slag is produced at a rate of about 10 t per ton of elemental phosphorus, while ferrophosphorus is produced at a rate of about 0.3 t per ton of elemental phosphorus (EPA 1989 1989a).

5.3.1 Radioactivity Levels

5.3.1.1 Origin of Radioactivity

The concentrations of uranium in phosphate ores range from 20 to 300 ppm (or about 7 to 100 pCi/g) (DeVoto and Stevens 1979), while thorium occurs at essentially ambient background concentrations, between 1 to 5 ppm (or about 0.1 to 0.6 pCi/g) (Bliss 1988). Typical concentrations of uranium and radium in Florida phosphate rock are reported to be about 40 pCi/g (Guimond and Windham 1975). For the wet-process, Ra-226 is the highest in washer products, including clays and pebbles, ranging from about 26 to 57 pCi/g. Sand tailings contain less radioactivity, typically about 5 pCi/g of Ra-226. The process concentrates contain about the same concentration of Ra-226 as the phosphate rock, nearly 40 pCi/g. Some of the wastes, e.g., scale and sediments, can also be found deposited in ancillary piping and filtrate receiver tanks associated with the filtration process and may accumulate radioactivity over time.

Radionuclide concentrations in phosphogypsum and other wastes (such as filter and scale) have been reported to vary as follows:

Phosphogypsum: Ra-226: 17 - 33 pCi/g (27 pCi/g average)

Process Scale: Ra-226: 1,000 - 6,200 pCi/g (2,300 pCi/g average)
Ra-228: 5- 630 pCi/g (214 pCi/g average)
Pb-210: 470 - 2,300 pCi/g (1,100 pCi/g average)

The concentrations of Th-232 are reportedly low in both phosphate rock and phosphogypsum. In phosphate rock, Th-232 concentrations were noted to vary from 0.66 to 3.2 pCi/g, with an average of 1.6 ± 0.8 pCi/g, based on 11 samples (FIPR 1995). In phosphogypsum, Th-232 levels were lower still, varying from 0.12 to 1.34 pCi/g and averaging 0.42 ± 0.35 pCi/g, based on 17 samples (FIPR 1995).

For Ra-226, concentrations in phosphatic clays range from about 7 to 54 pCi/g-dry, and near secular equilibrium exists between U-238/U-234, Ra-226, and Th-230 (Guimond and Windham 1975, Stricker et al. 1991, Hanlon 1991, Million et al. 1994, Shibles and Riddle 1994). Similar results were noted for Pb-210 (13 - 59 pCi/g) and Po-210 (10 - 49 pCi/g) (Shibles and Riddle 1994). For sand tailings, Pb-210 and Po-210 concentrations are lower, ranging from 2 to 8 pCi/g (Guimond and Windham 1975, Million et al. 1994).

In some instances, Ra-226 concentrations have been reported to reach as high as 100,000 pCi/g in scales and residues found on filter pans and fiberglass mats (Keaton 1988). While the concentrations of scales and residues are higher than those of phosphogypsum, their waste volumes are relatively small.

In the thermal process, the radioactivity is contained in the slag, with U-238 and Ra-226 being on the order of 60 pCi/g each (Roessler et al. 1979). In ferrophosphorus, Ra-226 concentrations are lower than those in U-238, about 2 and 40 pCi/g, respectively. The coke used as a feedstock has been estimated to contain low Ra-226 and U-238 concentrations, about 1 and 2 pCi/g, respectively. Because of the high temperatures involved in the process, most of Bi-212, Bi-214, Po-210, and Pb-210 is volatilized, along with radon (EPA 1981 and 1981a).

The concentrations of radioactivity vary by types of fertilizers and production processes, with average concentrations ranging from approximately 5 to 20 pCi/g of Ra-226, 20 to 60 pCi/g of U-238 and U-234, and 1 to 3 pCi/g of Th-232 (EPA 1997b). Table 5-8 presents radionuclide concentrations typically found in fertilizer constituents.

Given that there are hundreds of different blends of fertilizers, it is difficult to identify one that would typify radiological properties or even ranges of radionuclide concentrations. Different

fertilizer blends are made by mixing mono-ammonium phosphate, di-ammonium phosphate, normal superphosphate, and triple superphosphate in various proportions. Fertilizers also include other nutrients that contain nitrogen and potassium. However, the weighted (based on fertilizer production rates) concentrations are about 53 pCi/g for U-238, 5.7 pCi/g Ra-226, 4 pCi/g each for Pb-210 and Po-210, and 1.1 pCi/g for Th-232 (EPA 1997b).

The source of potassium in fertilizers is generally potash which naturally contains K-40. The abundance of K-40 in potassium is 0.0118 percent, which corresponds to a specific activity of about 840 pCi/g-potassium (CRC 1995c). The activity of K-40 in potash depends on the quantity of potassium present, which is usually expressed as equivalent mass of K₂O at about 696 pCi/g. Since potash contains about 60 percent K₂O, the actual K-40 concentration in potash is about 420 pCi/g. In soils, the concentration of K-40 is about 20 pCi/g, assuming a content of 2.4 percent for potassium in the earth's crust.

Table 5-8. Typical Fertilizer Radionuclide Concentrations^(a)

| Material | Concentration (pCi/g) | | | | |
|--|-----------------------|-------|----------------|--------|--------|
| | Ra-226 | U-238 | U-234 | Th-230 | Th-232 |
| Normal superphosphate | 21 | 20 | ^(b) | 18 | 0.6 |
| Triple superphosphate | 19 | 51 | 51 | 43 | 0.4 |
| Di-ammonium phosphate | 6 | 63 | 63 | 65 | 0.4 |
| Mono-ammonium phosphate | 5 | 55 | 55 | 50 | 1.7 |
| Phosphoric Acid (29% P ₂ O ₅) - pCi/L | 0.5 | 25 | ^(b) | 28 | 3.1 |

a Source: EPA 1997b. Made with typical Florida phosphate rock.

b Secular equilibrium with U-238 assumed.

Wastes generated during the production of potash include sediments and residues deposited in ancillary piping and tanks and associated filtration processes. Since processing relies more on physical processes, such as flotation, separation, and selective crystallization and less on chemical conversions, the resulting wastes are not generally characterized by radionuclide speciation in specific waste streams.

5.3.1.2 External Radiation Levels Near Processing and Waste Handling Equipment

Measurements made on the top of phosphogypsum stacks revealed exposure rates ranging from 26 µR/h to 50 µR/h, with an average of 33 µR/h, based on data from five stacks (Texas Instruments 1978, Horton 1988). Radiation surveys conducted around large volumes of

phosphate ores have revealed exposure rates ranging from 20 to 100 $\mu\text{R/h}$, with an average of 60 $\mu\text{R/h}$ (Texas Instruments 1978). Elevated radiation levels (up to 5,000 $\mu\text{R/h}$) around filter pans have also been noted, especially when the pans are loaded with scale and residues containing elevated levels of radium (Keaton 1988, Texas Instruments 1978). In comparison, typical ambient exposure rates due to background radioactivity vary from 5 to 10 $\mu\text{R/h}$ in Florida (Horton et al. 1988).

Radiation surveys conducted near phosphate slag piles have revealed elevated external radiation exposure rates (EPA 1990 and 1990a; Hendricks 1994). Exposure rates of about 100 $\mu\text{R/h}$ have been measured near outdoor slag piles at a plant located in Pocatello, Idaho (EPA 1990 and 1990a). Similarly elevated levels were found in Montana and Idaho, where slag from elemental phosphorus plants was used to pave streets and incorporated into building material. Ambient radiation levels in streets paved with slag have been noted to vary from 28 to 50 $\mu\text{R/h}$ (EPA 1983a). Radiation levels as high as 65 $\mu\text{R/h}$ have been measured in some homes and nearly 100 $\mu\text{R/h}$ in a church (EPA 1983a, CRCPD 1981).

5.3.1.3 Residual Levels of Radioactivity in Equipment Released for Recycling

There is no information with which to characterize residual levels of radioactivity that may be present in equipment released for recycling. The levels of radioactivity describing the presence of radium in process streams could be used to infer similar levels in equipment. Based on the data presented earlier, it is assumed that residual radioactivity levels (pCi/g) present in surface films on equipment could be distributed as described in Table 5-9.

Table 5-9. Radionuclide Concentrations in Surface Films (pCi/g)

| Related Equipment | U-238 | Ra-226 | Po/Pb-210 | Th-232 | Ra-228 | K-40 |
|-----------------------|---------|---------------|-------------|-----------|---------|-----------|
| Phosphogypsum | 2 - 5 | 15 - 30 | 20 - 40 | 0.1 - 1 | -- | -- |
| Scale Filtration | -- | 1,000 - 6,000 | 500 - 2,000 | -- | 5 - 600 | -- |
| Thermal process | 20 - 60 | 20 - 60 | 1 - 7 | 0.2 - 0.5 | -- | -- |
| Fertilizer production | 50 | 6 | 4 | 1 | -- | 400 - 700 |

5.3.2 Quantities of Contaminated Scrap Material

For the wet-process, phosphogypsum is transferred as a slurry to disposal areas, known as phosphogypsum stacks. Stacks are very large structures, ranging in size from 2 to 300 hectares and 3 to 60 meters in height. The stacks are built over virgin land or previously mined areas. Each facility may use several stacks, depending on production rates. Other waste generated by the wet process includes material and sludge/sands/scale that are periodically taken out of the system. The smaller amounts of these wastes are, at times, much higher in radioactivity levels. Such wastes are routinely disposed of by burial in stacks. Phosphogypsum is being used as a source of calcium in agricultural applications, for soil amendment, and in road construction as a concrete aggregate and fill for road base.

The largest amount of waste generated by the thermal process is a glassy slag. The slag is stored on site, although some slag is routinely being used in various applications as concrete and asphalt aggregates for road construction and as railroad ballast. Another product, ferrophosphorous, is being used by the steel industry and in paint pigments.

There are no estimates of the amount of scrap metal that this industry sector generates. For the wet-process, it is expected that process equipment may contain both low and elevated levels of radioactivity. The higher levels of radioactivity are confined to stainless steel filter pans, while lower levels of radioactivity are more prevalently distributed to various parts of the process equipment. Process equipment includes conveyor belts, washer/flotation units, dryers, tanks, vessels, pumps, piping, valves, and instrumentation. Some of the process vessels and tanks are internally lined with vulcanized rubber. Slurry pipe lines, several miles in length, are also expected to contain residual levels of radioactivity since they are used to convey phosphogypsum from the plant to phosphogypsum stacks. Slurry pipes are periodically replaced as they wear out internally from the abrasive flow of the phosphogypsum. Pipes are rotated to lengthen their operational life.

In the thermal process, the materials include equipment associated with the operation of furnaces and calciners. The wastes include refractory bricks and parts of the charging and ventilation systems. Except for refractory liners, furnace and calciner components are replaced only infrequently.

5.4 Coal Ash from Fossil Fuel Combustion

Fossil fuels, such as coal, oil, and gas, are commonly used as the energy source for electric power plants. The heat is used to generate steam in boilers to run turbines and generators for producing electricity. An electric utility steam-generating unit is defined as any fossil-fuel-fired combustion unit of more than 25 MW(e) that serves a generator producing electricity for sale (Clean Air Act, Section 112(a)(8)). About 2,300 fossil-fueled power plants operate in the United States, of which 1,250 use coal, 329 use oil, and 719 use natural gas (EPA 1992a, 1996a, 1997b). Coal-fired power plants represent about 66 percent of the industry's total power output, as compared to 24 percent for gas-fired and 10 percent for oil-fired units. The 2,300 fossil-fuel-fired power plants are located at 684 utility sites, some with multiple units (EPA 1996a).

Elements common to all fossil-fuel-fired plants include a boiler, steam turbine, generator, water cooling system, fuel preparation and processing equipment, and assorted auxiliary systems. The combustion of coal results in the generation of ash, most of which is retained in handling systems, as bottom ash and slag. A small fraction of the ash (fly ash) is released in the environment via plant stacks. Plant and system components that are fuel specific relate to furnace design, formation and collection of ash, and flue gas emission controls. Emission control methods rely on electrostatic precipitators, mechanical collectors, baghouses, and flue gas desulfurization units using both dry and wet scrubbers. The design features and operating parameters of a coal furnace are considerably different from those of a furnace using oil or natural gas. The relatively high ash content of coal requires specific systems for handling ash that remains in the furnace or gets entrained in the combustion gases. The amount of waste (as bottom ash, fly ash, slag, and scrubber sludge) has increased steadily over the years from about 30 million metric tons in 1968 to 60 million metric tons in 1997 (ACAA 1997, EPA 1997b).

Electric utilities use three major types of coal: bituminous, sub-bituminous, and lignite. The designations reflect chemical composition and geographic origin. The combustion of coal generates an ash which includes all noncombustible mineral matter, including most of the naturally occurring radionuclides. Wastes generated by electric utility units and radionuclide distribution among waste products are directly affected by the composition of the fossil fuel, boiler design, operating practices, and type of flue gas treatment system. These aspects, in part, govern how much radioactivity remains in bottom ash, hardened slag on inner boiler surfaces, or is attached to fly ash.

5.4.1 Radioactivity Levels

5.4.1.1 Origin of the Radioactivity

Coal contains trace amounts of naturally occurring radionuclides, including the U- and Th-series, as well as their associated decay products, and K-40. The presence and concentrations of specific radionuclides are not unique when compared to other natural material, as it is generally assumed that average radioactivity levels in soils and rocks are about twice that of coal (UNS 1982). The concentration of U-238 and Th-232 in coal is estimated to vary from 0.003 to 25 pCi/g and from 0.001 to 8.7 pCi/g, respectively. However, radionuclide concentrations are higher in ash, by a factor of about 10, than in coal depending on the mineral content of the coal and type of boiler. This factor reflects the ratio of the noncombustible mineral and combustible organic components of coal. Although the literature notes that coal sometimes contains elevated levels of radioactivity, the wide range of radionuclide concentrations and isolated instances of high concentrations are evened out by the use of several sources of coal and the dilution factor afforded by the large amount of ash (about 63,000 metric tons annually) produced by a typical power plant. Radionuclide concentrations in coal ash have been estimated to average about 4.0 pCi/g for U-238, 2.4 pCi/g for Th-232, and 4.0 pCi/g for Ra-226 (EPA 1997b). The range of each has been estimated as 2.2 to 7.3 pCi/g for U-238, 1.2 to 4.8 pCi/g for Th-232, and 2.2 to 7.3 pCi/g for Ra-226.

In natural gas, the presence and concentration of radon (Rn-222) is known to vary from about 10 to 200 pCi/L, with an average of nearly 40 pCi/L at the wellhead (EPA 1992a). However, radon concentrations are typically lower at the point of use. The reduction in concentration is due, in part, on production rate, processing method, pipeline transmission time, and storage time before use. Radon levels at the point of use vary as well, ranging from 0.5 to 100 pCi/L, with an average of 20 pCi/L (EPA 1992a). For gas-fired power plants, it is simply assumed that all of the radon present in the natural gas is released through the stack. Accordingly, the amounts of ash produced by gas-fired power plants are not relevant.

Like coal and gas, oil contains trace amounts of uranium and thorium and their respective decay products. In 24 oil samples, the concentration of uranium has been reported to range from 7.0×10^{-6} to 0.045 pCi/g (EPA 1992a). An analysis of 13 crude oil samples revealed U-238 concentrations of 0.005 pCi/g and 0.011 pCi/g for Th-232. The presence of radioactivity has also been evaluated in residual fuel oils, with estimates of 0.7 ppm for U and 0.03 ppm for Th. The

average radionuclide concentration in 28 residual fuel oil samples was estimated to be 0.13 pCi/g for U-238, 0.39 pCi/g for Ra-226, 0.02 pCi/g for Th-232, and 0.30 pCi/g for Ra-228 (EPA 1992a). The overall range of radioactivity levels in crude oil is estimated to vary from 0.0002 to 0.005 pCi/g for U-238 and less than 0.011 pCi/g for Th-232. For residual fuel oils, radioactivity levels are estimated to vary from 0.0006 to 0.23 pCi/g for U-238 and from 0.003 to 0.02 pCi/g for Th-232. The concentration of K-40 has also been found to be very low in fuel oil, typically about 0.04 pCi/g.

The use of oil in power plants generates an ash consisting mainly of metallic oxides and salts. The amount of U-238 in ash is estimated to be about 0.001 pCi/g. The ash content of fuel oil is estimated to vary from about 0.0015 to 0.11 percent by weight, with an assumed average of about 0.1 percent. Oil-fired power plants generate very small amounts of ash, as compared to coal-fired power plants. As with gas fired-power plants, most oil-fired power plants do not use particulate emission control systems.

5.4.1.2 External Radiation Levels Near Ash Handling and Processing Equipment

There is no information characterizing radiation levels on or near ash handling systems at coal-fired power plants. Given the low concentrations of U, Th, and Ra, radiation levels would likely be undistinguishable from ambient background levels.

5.4.1.3 Residual Levels of Radioactivity in Equipment Released for Recycling

Given the relatively low levels of radioactivity in coal ash, it may be presumed that similar levels of residual radioactivity would be found in equipment. Residual radioactivity levels in surface films on equipment are assumed to vary from 2.2 to 7.3 pCi/g for U-238, 1.2 to 4.8 pCi/g for Th-232, and 2.2 to 7.3 pCi/g for Ra-226.

5.4.2 Quantities of Contaminated Scrap Material

Two types of ash collection systems are used in coal boilers—dry-bottom or wet-bottom. A dry-bottom collector may use either hydraulic, mechanical, or pneumatic equipment to remove slag clinkers or dry ash. In a hydraulic system, the dry material drops into the bottom ash bins and is removed by water jets that suspend the ash. The bottom ash is pumped to a holding tank and either transferred from the plant in a slurry form or dewatered and removed as a solid. In a

mechanical system, the bottom ash drops from a collection bin into a water tank. A conveyor carries the bottom ash and dumps it onto a conveyor, which takes it to a discharge area or temporary storage facility. In the pneumatic system, hot ash is suspended in a vacuum and transported to a dry storage area. With the wet-bottom collection system, slag drops to the bottom of the boiler in a molten pool of slag, which is kept molten by dropping furnace flames.

Pulverized coal boilers commonly use coal with low potential for slagging and, therefore, employ dry-bottom ash collection. In most cyclone boilers (and in a limited number of pulverized coal boilers that use coal with high slagging potential), a wet-bottom design is used. Nearly 87 percent of currently operating units use dry-bottom collection systems.

Coal combustion byproducts are being used in various applications, given the relatively uniform small particle size of coal ash, surface reactivity, and bulk chemical composition. Coal ash, slag, and flue gas desulfurization sludge have been used in cement and concrete products; flowable and structural fill; road base/subbase; coal mining applications; mineral filler in asphalt; snow and ice road control; blasting grid and roofing granules; grouting; waste solidification and stabilization; wall board; and miscellaneous other applications. On average, 25 percent of the fly and bottom ash, boiler slag, and flue gas desulfurization sludge produced is used in such applications. Ash and other material that are not used are placed in surface impoundments or landfills. In surface impoundments, the ash is pumped as a slurry using pipelines. In landfills, the material is shipped dry and buried in disposal cells.

There are no details on the management practices of utilities regarding the disposition of plant equipment. It is assumed that as part of routine maintenance, certain boiler components are routinely replaced, including furnace grates and some portions of the ash handling system. Other systems that may require periodic refurbishment include tanks, pumps, and pipelines used to pump ash slurries to settling ponds and impoundments. The replacement frequency of such equipment and related amounts of scrap metal that could be recycled are unknown.

5.5 Drinking Water Treatment

Of the approximately 55,600 community water-supply systems, 44,800 rely on groundwater sources (EPA 1997). Community water-supply systems are publicly or privately owned utilities. In addition, a number of small community water-supply systems are owned by mobile-home parks and homeowner associations. Other distribution systems include non-community water-

supply systems serving restaurants, camp grounds, service stations, motels and hotels, schools, factories, hospitals, and other institutions (EPA 1997).

Water is treated by using various types of filtration techniques that rely on physical and chemical processes to remove organic and inorganic impurities and organisms. When water containing naturally occurring radioactivity is treated, the resulting residues contain some amounts of radioactivity, even if treatment systems were not originally designed to remove it. Such wastes include filter sludge, ion-exchange resins, granular activated carbon, and waste water from filter backwash. Given that about 81 billion gallons of groundwater are used daily, possibly significant amounts of treatment residues containing naturally occurring radioactivity may be generated.

5.5.1 Radioactivity Levels

5.5.1.1 Origin of the Radioactivity

Since water comes from a variety of sources, including streams, lakes, reservoirs, and aquifers, it contains varying levels of naturally occurring radioactivity. Radioactivity is leached and entrained into ground or surface water, when water comes in contact with geologic media bearing uranium and thorium. The predominant radionuclides found in water include radium, uranium, and radon, as well as their radioactive decay products. Natural conditions, such as groundwater pH, redox potential, radionuclide solubility and half-life, as well as water withdrawal rates, directly affect the concentrations and distributions of naturally occurring radionuclides.

Groundwater sources containing elevated levels of radioactivity tend to be located in regional clusters characterized by igneous rocks, metamorphic rocks, and sandstone (Hess et al. 1985). High radium concentrations are often associated with groundwater drawn from aquifers in sandstone, shale, and dolomite (Gilkeson et al. 1984). Higher uranium levels are often associated with groundwater drawn from aquifers in granite and shale, while aquifers in sandstone are often characterized by low uranium concentrations (Castle 1988). However, the prediction of water concentrations relying solely on aquifer lithology has been deemed unreliable because dissolved radionuclides are significantly affected by other factors, such as pH, Eh, pore volume, and temperature (Deutsch and Serne 1984). Accordingly, the distribution and concentrations of dissolved uranium and radium are believed to be mainly governed by groundwater chemistry.

Based on EPA data, three regions in the United States appear to be characterized by elevated radionuclide concentrations in groundwater (Horton 1985). The first region is associated with

groundwater that contains higher levels of Ra-226 and Ra-228, extending from the northwest areas of Georgia and South Carolina to Minnesota, and as far west as Kansas. Groundwater concentration levels in this region are similar to those noted in the North Central, Piedmont, and Coastal Plain Regions, which include the States of Illinois, Iowa, Minnesota, Missouri, Wisconsin, New Jersey, North Carolina, South Carolina, and Georgia (Cothorn and Lappenbusch 1983, 1984; Hess et al. 1985; Lowry and Lowry 1988). The second region is associated with groundwater containing higher U-238 and U-234 concentrations. This region consists mainly of Western States, including Colorado, Wyoming, Montana, Oklahoma, New Mexico, Idaho, and South Dakota. The third region includes Northeast States, where existing groundwater contains higher levels of Rn-222. These States include New Hampshire, Rhode Island, Maine, Connecticut, Massachusetts, Pennsylvania, and Vermont. Table 5-10 summarizes the range of radionuclide concentrations observed in some groundwater samples.

Table 5-10. Typical Radionuclide Concentrations in Groundwater

| Radionuclide | Range (pCi/L) | Peak Conc. (pCi/L) |
|------------------------|---------------|----------------------|
| Ra-226 | 0.5 - 25 | 200 |
| Ra-228 | 0 - 13 | 54 (as Ra-226 + 228) |
| U-238 + U-234 | 0 - 40 | 652 |
| Th-232, Th-230, Th-234 | 0.01 - 0.04 | <0.1 |
| Rn-222 | 69 - 9,200 | 16,000 |

Source: Lowry et al. 1987a; Lowry 1987b; Lowry and Lowry 1988; Horton 1985; Hess et al. 1985; Reid et al. 1985; Szabo and Zapecza 1987; EPA 1986a; Cothorn and Lappenbusch 1983, 1984; Longtin 1987; EPA 1997b.

Given this information, it is assumed that water-supply systems relying on groundwater within these regions would more likely produce NORM-contaminated water treatment wastes.

Table 5-11 summarizes the range of radionuclide concentrations observed in water treatment wastes.

The types of water treatment methods (EPA 1996b) used fall into three major categories:

- Coagulation, filter backwashing, lime softening, iron removal, and sand filtering. Waste includes sludge, which is mostly water with some suspended solids.
- Ion-exchange and salt water conversion. Wastes include concentrated brine, reject water, backwash, and spent resins.
- Granular activated carbon bed. Wastes include spent carbon and backwash.

Table 5-11. Typical Radionuclide Concentrations in Water Treatment Waste

| Waste | Process | Ra-226 Conc. (pCi/L) |
|------------------------|-----------------|-------------------------------------|
| Backwash | Lime softening | 6.3 - 92 |
| Brine | Ion-exchange | 6 - 30 |
| Reject water | Reverse osmosis | 7.8 - 43 |
| Sludge - Low Activity | Precipitation | 0.2 - 23 |
| Sludge - High Activity | Precipitation | 980 - 4,577 |
| Spent resins | Ion-Exchange | 6.0 - 3,600 |
| Spent carbon media | Carbon Bed | U: 549 - 9,050 Pb-210: up to 755 |

Source: EPA 1996b, 1997b.

Lime softening is used at larger supply systems to soften water by the addition of calcium hydroxide, which causes calcium and magnesium to precipitate out. The precipitate, along with suspended solids, is removed by sedimentation and filtration. About 80 to 90 percent of radium present in water is also collected in the resulting sludge (Hahn 1988). This process produces about 3.1 m³ of dewatered sludge per million gallons of processed water (Hahn 1988). Prior to dewatering, sludge is about 2 to 5 percent solids by weight. After dewatering, sludge is about 16 percent solids on average, with a range of 3.1 to 55 percent (EPA 1986b, 1996b, 1997b). The bulk density of sludge is assumed to be about 1.2 g/cm³ (EPA 1996b).

Ion-exchange resins are used to soften water by replacing Ca²⁺ and Mg²⁺ ions with Na⁺ ions. In the process, about 95 percent of the radium is also removed (Hahn 1988). Ion-exchange yields waste with high specific activity levels. Resins are usually backwashed for reuse, rather than being disposed of. The backwash water, which contains radium, is typically discharged to sanitary or storm sewers, underground injection wells, or septic tanks. With time, radioactivity levels in resins tend to build up, depending on the radioactivity of the influent water and characteristics of the resins. Ra-226 concentrations ranging from 2 to 10⁺⁶ pCi/L have been observed (EPA 1997b).

The use of carbon filters results in the generation of spent carbon granules and similar types of waste waters. The removal efficiency of carbon beds is over 90 percent for radon, and the beds have been shown to capture radium and uranium. The presence of radioactivity in spent carbon has been reported to vary from 459 to 9,050 pCi/L for U and up to 755 pCi/L for Pb-210 (EPA 1997b).

Other types of water treatment processes are also known to remove radioactivity, but these methods have not been widely evaluated. For example, flocculation and coagulation, when combined with filtration, are believed to be effective in removing specific radionuclides with higher valences (Dyksen et al. 1986). Another approach is reverse osmosis, which is not widely used. Liquid waste generated by such a system include brines, backwash and reject waters, with Ra-226 concentrations ranging from about 5 to 12,000 pCi/L and uranium varying from 2.4 to 10^{+6} µg/L (Clifford et al. 1988, EPA 1982a).

The presence of Ra-226 in dry sludge has been noted to vary from 1.3 to 32.8 pCi/g, averaging about 11 pCi/g (EPA 1997b).

5.5.1.2 External Radiation Levels Near Water Treatment Waste Handling Equipment

There is no information characterizing radiation levels from equipment used to treat water and process the resulting sludge and sediments. For most wastes, radiation levels associated with the disposal of water treatment sludge are expected to be low, possibly comparable to ambient background radiation levels. However, exposure rates from spent resin and charcoal beds are expected to be much higher. For example, exposure levels as high as several mR/h have been observed on charcoal and resin beds (Lowry and Lowry 1988; Lowry et al. 1987a). Depending on the source of radioactivity (radium vs. radon decay products), radiation levels may quickly decay with time.

5.5.1.3 Residual Levels of Radioactivity in Equipment Released for Recycling

There is no information characterizing residual levels of radioactivity in water processing and waste handling equipment used at community and non-community water supply systems. Given the relatively low levels of radioactivity in most sludge, it is assumed that similar levels of residual radioactivity would be found in such equipment. Residual Ra-226 radioactivity levels on equipment surfaces, due to low-activity sludge, are assumed to vary from 1.3 to 32.8 pCi/g-dry, with an average of about 11 pCi/g-dry. For equipment that once contained higher activity wastes, e.g., ion-exchange columns and carbon beds, it is expected that residual levels of radioactivity would be much higher, possibly by a few orders of magnitude, than those noted for dry sludge.

5.5.2 Quantities of Contaminated Scrap Material

Seven methods are most commonly used to treat water. Table 5-12 presents a summary of water treatment systems most often used by 211 water utilities (AWWA 1987). The data reflect 1985 operating practices, based on a survey conducted by the American Water Works Association (AWWA). The four types of treatment methods most often used are chemical treatment, filtration, coagulation and flocculation, and sedimentation. These methods are likely to generate some contaminated waste as they are effective in removing radioactivity and producing sludge (EPA 1996b, 1994). The remaining treatment methods generate little sludge or are not known to remove significant amounts of radioactivity (Lowry et al. 1987a, EPA 1997b). The seven waste disposal methods commonly used by water utilities and supply systems include the following (EPA 1996b, 1994):

- Disposal in Lagoons
- Disposal in Sanitary Sewer
- Deep-Well Injection
- Land Spreading/Soil Conditioning
- Disposal in Landfills
- Disposal in Storm Sewers
- Septic System

Table 5-12. Water Treatment Processing Methods Reported by 211 Water Utilities

| Treatment Method | Cited Use | Percent of Total |
|-------------------------------------|-----------|------------------|
| Chemical | 253 | 40.9 |
| Greensand filtration | 111 | 18.0 |
| Coagulation and flocculation | 86 | 13.9 |
| Sedimentation | 76 | 12.3 |
| Lime and soda lime softening | 34 | 5.5 |
| Aeration and volatilization | 33 | 5.3 |
| Ion exchange and activated charcoal | 25 | 4.1 |
| Total | 618 | 100.0 |

Note: Adapted from EPA 1997b. Data characterize practices of 184 utilities reporting the use of 20 water treatment techniques. A total of 27 utilities (13%) reported using no treatment methods at all, while others use several treatment methods at the same time. Information and data extracted from the 1985 Water Utility Operating Data (AWWA 1987).

The EPA has estimated that community and non-community supply systems generate about 870,000 t of sludge, of which 260,000 t is believed to contain elevated levels of radioactivity (EPA 1997b). However, the EPA report does not estimate the potential amounts of scrap metal

that might be generated by the maintenance of water treatment systems and waste handling equipment.

There is no information on management practices of community and non-community water supply systems for the handling and disposition of water treatment and waste handling equipment. It is assumed that some components are replaced frequently, such as pumps, valves, hopper scrapers, filters and strainers, and parts from grit classifiers, belt filter presses, conveyors, and cyclone and centrifuge separators. However, the replacement frequency of such equipment and related amounts of scrap metal that could be recycled are unknown.

5.6 Metal and Mineral Mining and Processing

Depending on the origin of the ores, beneficiation methods, and initial levels of naturally occurring radioactivity, some of the process wastes from mining operations (other than from uranium ores discussed in Section 5.2) may contain varying levels of radioactivity (DOI 1987, EPA 1985, EPA 1997b). The radioactivity is associated with two radioactive decay series, U and Th. The major radionuclides include U-238, U-234, Th-230, Ra-226, Rn-222, Pb-210, Po-210 for the U-series; and Th-232, Ra-228, Ac-228, Th-228, and Ra-224 for the Th-series. In some situations, the actinium decay series may need to be considered as well, if U-238 is present at elevated concentrations. The major decay products of the actinium series include Th-231, Pa-231, Ac-227, Th-227, Ra-223, and Rn-219. Finally, potassium (as K-40) is also included, as it could be present at elevated concentrations in feedstock or in process wastes.

Table 5-13 lists the production levels of metallic ores that are known to have or suspected of having potentially elevated radionuclide concentrations in either the ores themselves or process wastes. Such metallic ores include copper, gold, lead, iron, molybdenum, silver, and zinc. The category "Others" includes beryllium, gold/silver, manganiferous ores, platinum and palladium, rare-earth concentrates, titanium, uranium, and other metals for which producers withheld data (USGS 1999). Bauxite is not included, as the United States imports over 99 percent of its needs, and the data on U.S. production is withheld by producers (USGS 1999).

Geologists generally agree that the levels of radioactivity found in ores depend more on the type of geologic formation than on the particular type of mineral or metallic ores. Ores often contain several minerals, and the presence of radioactivity is not necessarily representative of other minerals mined at other geographical locations. Because U-rich ores (e.g., uraninite or autunite)

have been found in abandoned and closed precious metal mines and related mine wastes, it is assumed that some ores and beneficiation wastes may also be characterized by elevated levels of radioactivity. The literature provides only limited information about radioactivity present in metallic and mineral ores (e.g., CRC 1989, 1995b; Brady et al. 1997; CRCPD 1981, 1994; EPA 1985, 1990a, 1996c, 1997b). Typically, the information does not fully address the presence of radioactivity and radionuclide distributions and concentrations by types of ore processing methods and wastes.

Table 5-13. Domestic Crude Ore and Mining Waste Production - 1997^(a)

| Metal/Mineral Ore | Crude Ores | Mining Waste | Total (million t) |
|------------------------------------|------------|--------------|----------------------|
| Copper | 674 | 636 | 1,310 |
| Gold | 263 | 841 | 1,100 |
| Lead (after smelting and refining) | (b) | (b) | 0.448 |
| Iron | 210 | 179 | 388 |
| Molybdenum | 7.7 | 10 | 17.8 |
| Silver | 1.28 | 1.29 | 2.57 |
| Zinc | 5.4 | 0.997 | 6.39 |
| Others(c) | 68.7 | 29.1 | 97.8 |

a Adapted from EPA 1996c, EPA 1997b, and USGS Mineral Industry Surveys (USGS 1998, 1999).

b No data; information withheld by producers for proprietary reasons.

c The category "Others" includes beryllium, gold/silver, manganiferous ores, platinum and palladium, rare-earth concentrates, titanium, uranium, and other metals for which producers withheld data (USGS 1999).

5.6.1 Radioactivity Levels

5.6.1.1 Origin of the Radioactivity

The levels of radioactivity in ores are known to vary significantly, depending on the mineralogy of the geologic formation from which the ores are taken and geochemical processes favoring the accumulation of uranium and thorium. The presence of uranium or thorium varies over five orders of magnitude, from 0.0002 percent to 88 percent, in minerals and rocks (CRC 1989, Brady et al. 1997). Table 5-14 summarizes radioactivity levels found in mineral and metallic mining wastes (EPA 1997b). The data are presented by grouping ores and wastes into three categories, reflecting a natural distribution spanning three orders of magnitude. In some instances, there are waste streams that have much higher radionuclide concentration levels, at times several orders of

magnitude greater than noted here; however, the related waste volume is usually small as compared to that associated with most waste (EPA 1982, 1990a, 1997b; Andrews and Hendricks 1980; CRCPD 1981, 1987, 1994). Some processes associated with metal extraction and refining appear to concentrate certain radionuclides and enhance their environmental mobility in specific waste streams.

Table 5-14. Range and Best Estimate of Radioactivity Levels (pCi/g)
Found in Metal and Mineral Processing Wastes

| Metal/Mineral | U-238 | Ra-226 | Th-232 | Ra-228 |
|---|---------------------|---------------------|----------------------------|----------------------------|
| Metal and processing waste from rare earths mining/processing | <3,000 Ave.: 600 | <3,000 Ave.: 600 | 40 - 19,000 Ave.: 1,900 | 40 - 19,000 Ave.: 1,900 |
| Metal and processing waste Zr, Hf, Ti, Sn mining/processing | 3 - 100 Ave.: 30 | 3 - 100 Ave.: 30 | 3 - 100 Ave.: 20 | 3 - 100 Ave.: 20 |
| Metal and processing waste from Fe, Al, Cu mining/processing | 1 - 10 Ave.: 6 | 1 - 10 Ave.: 6 | 0.6 - 12 Ave.: 5 | 0.6 - 12 Ave.: 5 |

a - Adapted from EPA 1997b.

Essentially all mining and processing methods rely on the use of water, and instances of elevated levels of radioactivity have been found in process fluid streams and ground and surface water samples. In the copper industry, EPA studies have indicated that Ra-226 concentrations vary over three orders of magnitude in water samples, up to 100 pCi/L (EPA 1996). Uranium concentrations were found to range from 0.7 to 660 pCi/L, as U-238 (EPA 1996) and from 2 to 55 pCi/L for Ra-228. These results provide a perspective on the mobilization of radium and uranium in process fluid streams and the likelihood of internal contamination in process equipment.

5.6.1.2 External Radiation Levels Near Ore and Waste Handling Equipment

Radiation levels have been measured at some facilities. Typically, surveys were conducted to assess exposures to workers, as opposed to specifically characterizing radiation levels from process equipment or presence of large stockpiles of material or waste. In addition, the data do not indicate whether ambient radiation levels were more influenced by the presence of the material stockpiles or the process itself. Finally, there are no comprehensive data for the mineral or metallic ore mining sectors.

Gamma survey measurements made at a Texas tin smelter revealed radiation levels in slag storage areas ranging from 10 to 500 μ R/h, with average levels of less than 60 μ R/h (CRCPD

1981). Field measurements have revealed radiation levels of 10 to 120 $\mu\text{R/h}$ near large piles (~1,800 t) of zircon sands (CRCDP 1994). The zircon sands were reported to contain uranium at 75 to 100 pCi/g and thorium at 15 to 20 pCi/g. Survey measurements conducted at an ilmenite, zircon, and monazite processing plant located in Florida revealed ambient radiation levels varying from 20 to 360 $\mu\text{R/h}$ near equipment, including a dry mill (RGC 1996).

5.6.1.3 Residual Levels of Radioactivity in Equipment Released for Recycling

There is no specific information characterizing the presence and residual levels of radioactivity in mining, milling, beneficiation, and refining equipment used in this industrial sector. Given the widely ranging levels of radioactivity in some ores and process wastes, it is assumed that similar levels of residual radioactivity would be found in equipment. For low-activity ores and process streams, residual radioactivity levels present in equipment could vary from about 1 to 100 pCi/g for U-238, Ra-226, Th-232 and their decay products. For high specific activity ores and process streams, residual radioactivity levels might be as high as 3,000 pCi/g for U-238 and Ra-226 and their decay products and from 40 to 19,000 pCi/g for Th-232 and its decay products. For refining processes using high temperatures, such as furnaces and sintering and smelting plants, it is expected that the levels of Pb-210 and Po-210 would be lower in equipment that processed waste streams and products, but higher in waste handling and treatment equipment.

5.6.2 Quantities of Contaminated Scrap Material

Metallic ores and minerals are mined by both surface and underground methods. Some of the methods used by the uranium, coal, and phosphate mining industries are also applied in metal and mineral mining (EPA 1996c). Metallic ore mining operations involve the use of heavy equipment to extract and move ores, tailings, and wastes. The use of specific beneficiation methods depends on the properties of the ore or mineral and gangue, the presence of other minerals or metals in the same ore, and the relative costs of alternative processing methods. Some of the most common beneficiation methods rely on physical and chemical separation techniques, such as gravity concentration, magnetic separation, electrostatic separation, flotation, ion exchange, solvent extraction, electrowinning, precipitation, and amalgamation. For some ores (such as lead, zinc, titanium, and copper), subsequent processing and refining include the use of smelter, sinter, and electrolytic plants and fluidized bed reactors.

Most of the metal scrap generated by this industrial sector is expected to include structural steel used for the construction of process facilities and systems; ore crushers, grinders, separators, clarifiers, and conveyor systems; process vessels, tanks, leach pad sprinkler systems, and associated piping; pumps, valves, filters, strainers, ion-exchange columns, flow meters, and instrumentation. The bulk of the material will be ferrous metal. The replacement frequency of such equipment and related amounts of scrap metal that could be recycled by this industrial sector are unknown.

5.7 Geothermal Energy Production

Geothermal energy production relies on the heat energy stored or produced by the earth. This energy is associated with high temperatures found in rocks, volcanic deposits, water, and steam occurring at accessible depths. Although abundant, geothermal energy currently makes a relatively minor contribution to the total energy production of the United States.

Geothermal systems are located mostly in the western United States, primarily in California, Nevada, and Oregon. California is the single most important contributor (nearly 90 percent in 1994) to total electric power generation from geothermal energy. The Geysers in California is the largest vapor-dominated geothermal electrical generating complex in the world. Currently, 28 plants are in operation with a combined generating capacity of over 2,000 MW(e) (INEL 1997, Ballantine 1991, EPA 1987, EPA 1997b). However, the productive capacity of The Geysers field is expected to decrease as steam pressure is falling.

The heat is extracted by drilling wells in geothermal rock and bringing hot water and steam to the surface. Surface equipment includes steam turbines or heat exchangers and associated fluid handling equipment, and a disposal system (e.g., percolation ponds or reinjection wells).

During the extraction process, geothermal fluids containing dissolved and suspended constituents are brought to the surface. Changes in the thermodynamic properties, such as pressure, temperature, and volume, cause the precipitation of dissolved solids and release of gases. As a result, the fluids have different physical and chemical properties than the original water or steam. Although the solid waste generated during the drilling phase can be significant, precipitation and sedimentation from the geothermal fluids are the primary contributors to solid waste formation during operation. As with oil and gas extraction, scale can form by precipitation within the

equipment, both below and above ground. Sludge is formed by precipitation and sedimentation during the cooling process.

5.7.1 Radioactivity Levels

5.7.1.1 Origin of the Radioactivity

Naturally occurring radioactive materials, such as uranium, thorium, and their radioactive decay products and K-40, are present in underground formations from which geothermal fluids are extracted. Uranium and thorium are highly insoluble, while radium is slightly soluble and may be brought to the surface and become incorporated in scale or sludge. Radionuclide concentrations in geothermal waste vary with the types and locations of the geothermal resources and with the physical and chemical changes that take place during extraction. Important variables governing the physical and chemical changes are temperature, pressure, volume, and chemical composition of the fluid-rock-extraction equipment system. Since brines are ubiquitous in geothermal fluids, salinity plays an important role in determining the physical and chemical conditions in working fluids (Thomas and Gudmunson 1989).

Very little information is available on the concentrations of TENORM in geothermal solid waste, such as filter cakes, scale in piping and production equipment, and gases. The primary radionuclides present in geothermal fluids are Ra-224, Ra-226, Ra-228, Pb-210, Pb-212, and Rn-222 from the U-238 and Th-232 decay chains (Leslie et al. 1991). The only information on the presence and concentration of radioactivity in geothermal solid waste is contained in an Environmental Impact Report that provides the results of sample analyses from four geothermal power plants located in the Imperial Valley of California (ERC 1990). The data show Ra-226 concentrations ranging from 10 to 254 pCi/g, with an average of 132 ± 101 pCi/g and Ra-228 concentrations ranging from less than 9 to 183 pCi/g, with an average of 93 ± 70 pCi/g. For Th-228, concentrations were reported to vary from 6 to 44 pCi/g, with an average of 25 ± 16 pCi/g.

Radon concentrations in produced fluids and gases have been the subject of several studies (Reed 1976, Leslie et al. 1991). Radium concentrations in water have been reported to be 2,200 dpm for Ra-226 and 1,120 for Ra-228, based on flow tests which did not specify water volumes or flow rates (Leslie et al. 1991). Radon concentration levels in process fluids have been reported to vary from 8.3 to 16.7 pCi/L (Reed 1976).

5.7.1.2 External Radiation Levels Near Plant and Waste Handling Equipment

There is no information characterizing radiation levels around plant equipment during operations and during waste handling and processing.

5.7.1.3 Residual Levels of Radioactivity in Equipment Released for Recycling

There is no information characterizing residual levels of radioactivity present in equipment slated for recycling. Given the levels of radioactivity noted in some waste streams, it may be assumed that similar levels of residual radioactivity would be found in equipment. Residual radioactivity levels on equipment surfaces could vary from nondetectable levels to 250 pCi/g for Ra-226 and up to 183 pCi/g for Ra-228.

5.7.2 Quantities of Contaminated Scrap

Geothermal waste volumes are not well characterized since each utility conducts characterization or monitors plant performance to meet its specific needs. Also, the industry has not taken any steps to aggregate this information and release it publicly. A snapshot of the total waste generated in 1991 and its segregation into separate waste streams is given by Suess and Wardlow (1993). This information was obtained from an industry survey and represents the most comprehensive information available. The solid waste streams can be divided into four major components: filter cake (~41%), sulfur (~37%), drilling related (~21%), scale (~2%).

Liquid waste includes excess steam condensate from vapor-dominated systems and spent brines from liquid-dominated systems. Suspended and dissolved solids are removed from the liquid waste, and the liquids are reinjected into the reservoir.

Filter cake, produced from geothermal brines by filtration, precipitation, and sedimentation, is a waste typical of liquid- and vapor-dominated systems.

Sulfur is the next largest solid waste component of the total geothermal waste. Sulfur is produced during the abatement of H_2S at both vapor- and liquid-dominated plants. Hydrogen sulfide abatement constituents include iron sulfide sludge and iron catalysts used to precipitate hydrogen sulfide; emulsion waste from froth tanks, vanadium catalysts, and elemental sulfur

from the peroxide extraction process; and sulfur dioxide and sulfur dioxide diluted with water. In California, these wastes are incinerated or placed in a hazardous waste landfill.

Drilling operations require the use of special drilling mud, which produces cuttings mixed with drilling mud.

Scale represents the smallest contribution to the solid waste. During production, scale forms in process lines, valves, and turbines as the temperature and pressure are reduced and as the pH of the geothermal fluid changes due to the release of carbon dioxide. Typically, scale consists of barium, calcium, and strontium salts, and silica (carbonates, sulfates, and silicates). As in the case of oil and gas extraction, geothermal scale may contain varying levels of radium and its decay products. Significant efforts have been expended to investigate methods for mitigating scale formation by preventing precipitation of scale.

Gaseous wastes are generated by vapor- and liquid-dominated facilities, with H_2S and CO_2 being the primary components. A study (Tiangco 1995) indicated that the type of facility and heat extraction process play an important role in determining the presence and quantity of gaseous waste. Finally, radon (Rn-222) has been found in geothermal fluids as well and has been the subject of various studies (Kruger et al. 1977, Leslie et al. 1991, Reed 1976).

Wastes are exempt from RCRA but are regulated by State laws, as are the facilities located in the Imperial Valley and The Geysers. Regulatory and industrial efforts have focused on identifying waste properties, including chemical species, corrosivity, and chemical toxicity. However, limited attention has been paid to characterizing their radiological properties. An Environmental Impact Report, prepared in support of an application for a waste disposal facility located in California's Imperial Valley (ERC 1990), provides the only information on radionuclide distribution and concentrations in geothermal waste for a liquid-dominated system.

As for the other industry sectors, there is no information detailing industry practices for the disposal, reuse, and recycling of contaminated equipment. Equipment expected to be periodically replaced includes well casings, production well piping, manifolds, valves, pumps, filters, water clarifiers, tanks, and flash separators, solids separators, and instrumentation. The replacement frequency of such equipment and related amounts of scrap metal that could be recycled are unknown.

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