

## Chapter 5

### DESCRIPTION OF UNRESTRICTED RECYCLING OF CARBON STEEL

Chapter 2 presented an overview of scrap metal operations in the United States. The present chapter examines the recycling of carbon steel scrap in greater detail, with particular emphasis on those operations with the greatest potential for the radiation exposures of individuals.

#### 5.1 RECYCLING SCRAP STEEL—AN OVERVIEW

Figure 5-1 presents a simplified schematic diagram of some of the steps that would be involved in recycling carbon steel scrap into consumer or industrial products; this diagram is intended to present an outline of one possible set of recycling scenarios, which are discussed in this chapter. To preserve clarity, some of the scenarios addressed by the radiological assessment are not illustrated. For the sake of completeness, the following discussion makes note of additional or alternative steps in the recycling process which are not shown in the diagram nor addressed in the analysis. All references to these steps are enclosed by square brackets.

The process starts with radioactively contaminated steel scrap that is already stored in scrap piles at various DOE and perhaps at NRC-licensed facilities, or that will be generated in the course of the decommissioning of such facilities. [Smaller amounts of scrap are also generated during the normal operations of these facilities.] After initial decontamination to meet ALARA requirements, the scrap is surveyed to determine if it is a reasonable candidate for clearance. Scrap that does not satisfy a putative clearance criterion and that cannot be economically decontaminated to achieve such a criterion is disposed of as low-level radioactive waste. The remaining scrap is decontaminated as required and cleared for release; it is then loaded onto trucks [or rail cars] to be transported off site. As indicated on Figure 5-1, during these operations the material is under regulatory control. The tasks are performed by radiation workers, who are subject to DOE- or NRC-regulated exposure limits and ALARA procedures. Therefore, these operations are not addressed by the present analysis.

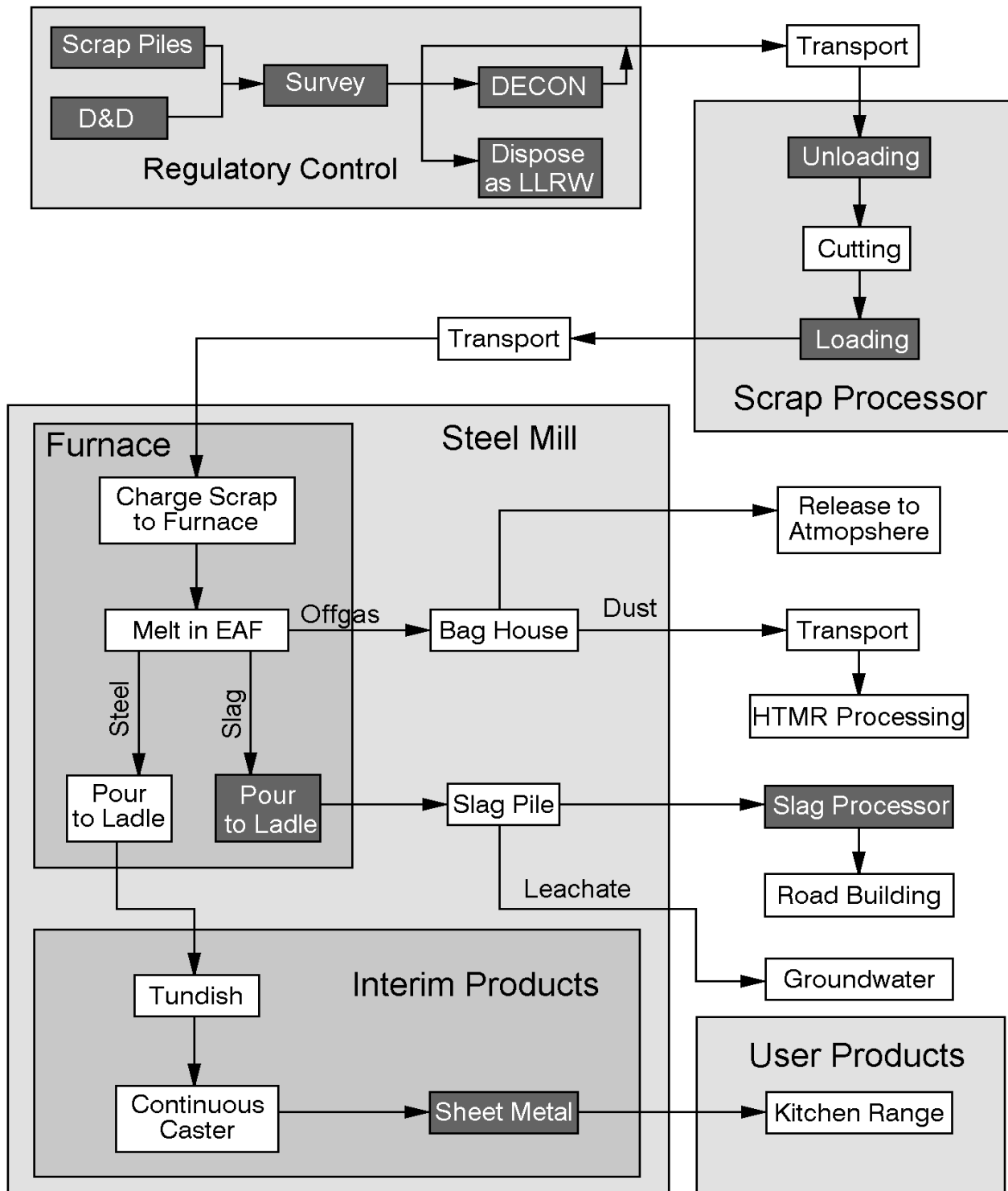


Figure 5-1. Operations Analyzed in the Carbon Steel Recycle Analysis  
 (Operations indicated by dark shaded boxes in the diagram are not modeled)

The scrap is transported to a processor where it is unloaded, sorted and possibly cut up or compacted. [Alternatively, it may be processed in a scrap staging area at or near the facility where the scrap was generated.] The processed scrap is transported to a steel mill where it may be [unloaded to a scrap pile or] sent directly to the furnace. In either case, it is loaded into a charging bucket and charged to an electric arc furnace (EAF), where it is melted.

Certain constituents of the furnace charge are either vaporized or entrained in the offgas as particulate matter. Most of these emissions are captured by the emission control system. Once inside the system, the fumes are routed to the baghouse, where they are cooled and filtered. The filters, which are in the form of long bags, are periodically emptied by remotely operated mechanical means. The dust is transferred to a tanker truck and shipped off site.

After the scrap is melted, first the slag and then the molten steel are poured into separate ladles. The molten steel is transferred from the ladle to a tundish from which it is fed to a continuous caster, where it is made into slabs. These may be sold as such or made into interim mill products, such as coils of sheet metal. The sheet metal may be made into consumer products, such as a kitchen range.

The slag is transported to a slag pile at the steel mill, where it is stored prior to shipment to a slag processing facility. The slag processor sells the slag for various uses, such as ballast for road-building or aggregate which is mixed with cement and used for paving. While the slag is stored at the mill, various components could leach out and percolate through the soil to an underlying aquifer, possibly contaminating an underground source of drinking water.

This list of scenarios, which follows the scrap from the generating facility to a specific consumer product, is only one of an endless set of possible variations in the process of recycling steel scrap. Not all possible scenarios could be analyzed, and, as stated earlier, not all scenarios that were analyzed are shown in Figure 5-1.

## 5.2 REFERENCE FACILITY

In the United States, most steel scrap is melted in either an EAF or a basic oxygen furnace (BOF). The charge for an EAF usually consists entirely of scrap, while scrap makes up less than 30% of the feedstock of a BOF, the rest being the pig iron output of a blast furnace. A steel mill equipped with EAFs was therefore selected as the reference mill for the present study.

The reference steel mill for the present analysis was based partly on the Calumet Steel Co. facility in Chicago Heights, Ill., which is described in greater detail in Appendix G. The mill is equipped with two EAFs, each of which has a 12.5-foot diameter shell and produces a 32-ton (29 t) average heat, with a nominal capacity of 75,000 tons (~68,000 t) per year. Other parameters used in the analysis are based on data pertaining to other facilities, on engineering judgement and on analytical assumptions. Thus, the reference steel mill is a hypothetical construct. This analysis should *not* be construed to predict that radioactively contaminated steel scrap will, in fact, be processed at any specific facility.

### 5.3 EXPOSURE PATHWAYS

The exposure pathways considered in the present analysis fall into two general groups: external exposure to direct penetrating radiation and internal exposure from inhaled or ingested radionuclides.

#### 5.3.1 External Exposure

The external exposures are evaluated by use of the MicroShield computer code, which is described in more detail in Section 6.3.1, or by dose coefficients adapted from Federal Guidance Report (FGR) No. 12 (Eckerman and Ryman 1993).

#### 5.3.2 Internal Exposure

The internal exposure pathways consist of the inhalation of radioactively contaminated dust, the inadvertent ingestion of contaminated dust, soot or other loose, finely divided material, and the ingestion of contaminated food or water.

The following sections describe the geometries and the materials used to model the external exposure from each task, as well as the assumptions regarding the inhalation and ingestion pathways. A detailed discussion of the last two pathways appears in Sections 6.3.2 and 6.3.3.

### 5.4 LIST OF OPERATIONS AND EXPOSURE SCENARIOS

Table 5-1 lists the operations and exposure parameters employed in the assessment of radiological impacts of recycling residually radioactive carbon steel scrap on exposed individuals. These operations and the parameters used to model the corresponding exposure

scenarios are partially based on an earlier EPA-sponsored study of the recycling of DOE scrap metal (SCA 1995). That study included over 60 exposure scenarios, which were based on studies done by the International Atomic Energy Agency (IAEA 1991) and for the NRC (O'Donnell et al. 1978), as well as on visits to steel mills and scrap processors and private communications with staff members of these facilities. The present analysis incorporates those operations shown to have the maximum potential impacts on the exposed individuals. This study included additional visits to steel mills and scrap processors, further communications with steel industry personnel, and additional research into scrap metal recycling practices. In addition to reviewing published and draft reports, valuable information and insights were obtained by close collaboration and consultation with other organizations which were also investigating the radiological consequences of the clearance of metals and other materials, including NRC, DOE, the European Commission, and the IAEA.

As seen in Table 5-1, the study addresses the radiation exposures from several representative finished products which might be made from recycled steel scrap<sup>1</sup>. These products were selected on the basis of their wide use and their potential radiological impacts on individuals—they are comparable to the finished products in the earlier studies. For many radionuclides, the impacts on end users would be dominated by exposure to external radiation. Therefore, the highest impacts would be produced by massive products that are in close proximity to the exposed individuals for the longest times. Cooking utensils were included to assess radiation exposures from consumption of food potentially contaminated by radionuclides leached from the metal during cooking.

---

<sup>1</sup> Three of these products are made from cast iron, which is produced by a different process than is used to make carbon steel. Since the radiological impacts of iron founding are not included in the present study, these products are not represented in Figure 5-1. However, the contaminant distributions characteristic of cast iron are utilized in the impact assessment of these products (see Section 6.2 and Appendix F).

Table 5-1. Exposure Scenarios and Parameters for Radiological Assessments of Individuals

Description	Dilution factor	Exposure Pathways							
		External Exposure			Internal				
		Time (hr/y)	Distance	Medium	Time (hr/y)	Medium	Dust load (mg/m <sup>3</sup> )	RF <sup>a</sup>	
<b>SCRAP TRANSPORT:</b> Truck Driver	0.2	1000	8 ft	scrap	N/A				
<b>SCRAP PROCESSING:</b> Cutter	0.055	1750	N/A <sup>b</sup>	scrap	1500		10	0.5	
<b>STEEL MILL</b>									
<b>Furnace Operations</b>									
Crane Operator	0.055	1750	10 m	scrap	1750	dust <sup>c</sup>	1.3	0.58	
EAF furnace operator		1750	4-30 ft <sup>d</sup>		1750		2.2		
Airborne effluent emissions		N/A							
<b>Interim Products</b>									
Operator of continuous caster	0.055	1750	2-15 ft	steel	1750	dust	2.0	0.58	
<b>Baghouse</b>									
Baghouse maintenance		1450	10 m	scrap	1450	dust	2.3	0.0076 <sup>f</sup>	
		40	<sup>e</sup>	dust	40		50		
		250	<sup>e</sup>		250		1.2		
Truck driver: baghouse dust		1000	3.5 m		N/A				
<b>Slag Pile</b>									
Slag pile worker	0.005	1000	N/A <sup>b</sup>	slag	1750	slag	2.6	0.51	
Slag leachate in groundwater		N/A							
<b>PROCESSING EAF DUST</b>	0.005	1000	N/A <sup>b</sup>	dust	1750	dust	10	0.5	
<b>INDUSTRIAL USE OF MILL PRODUCTS</b>									
Using slag in road construction	0.055	140	1 m	slag	1750	slag	2.6	0.51	
Assembling automobile engines		1750	20-70 cm	cast Fe	N/A				
Manufacturing industrial lathes		1750	20-70 cm		1750	cast Fe	2.7	0.5	
<b>END USERS</b>									
Using kitchen range	0.5	525	2 ft	steel	N/A				
Sailor on naval support vessel		2000	1.5 ft						
Taxi driver		3300	2 ft						
Lathe operator		1750	20-70 cm	cast Fe	N/A <sup>g</sup>	cast Fe	N/A		
Cooking in cast iron pan		263	2 ft						

<sup>a</sup> Respirable fraction

<sup>b</sup> Exposure assessment uses FGR 12 dose coefficients—see discussion in Section 6.3.1

<sup>c</sup> Dust = baghouse dust

<sup>d</sup> Range of distances—see discussion in Section 6.3.1

<sup>e</sup> Special model—see discussion in Appendix H

<sup>f</sup> Includes respiratory protection factor of 100

<sup>g</sup> Exposure from ingestion of contaminated food

### 5.4.1 Dilution Factors

Potentially contaminated scrap would in most cases be diluted with scrap that had never been exposed to radioactive contaminants. The ratio of the potentially contaminated scrap to the total amount of metal—termed the dilution factor<sup>2</sup>—is listed for each of the four major groups of operations shown in bold-faced upper-case type in Table 5-1. A detailed discussion of the dilution of scrap steel is presented in Appendix G. The section summarizes the application of these concepts to the scenarios presented in Table 5-1.

#### **Scrap Transport**

A truck driver could spend an entire year transporting the recyclable scrap metal from one large boiling-water reactor (BWR) power plant. However, as noted in Appendix G, only about 20% of such scrap would be potentially contaminated. Therefore, the average specific activity of any given radionuclide in the scrap being transported during the course of the year would be only 20% of its average specific activity in the potentially contaminated scrap. The dilution factor for the scrap transport operation is thus 0.2.

#### **Scrap Processing**

All the recyclable scrap metal from a BWR could plausibly be sent to a single scrap processor in a single year, resulting in the same dilution factor (0.2) as for the scrap transport operation, assuming that the processor accepts no scrap from other sources during that year. However, as discussed in Appendix G, the postulated decommissioning of the largest operating BWR power plant would only yield a total of about 38,000 t of carbon steel scrap—both clean and contaminated. The massive mountains of scrap which characterize this scenario, described later in this chapter, were observed at a facility that processed 50,000 tons (~45,000 t) per *month*—the exposure potential would most likely be much less at the smaller processor. If the approximately 7,500 t of potentially contaminated BWR scrap were sent to the larger facility, the dilution factor would be ~0.014. Although the actual size of the facility that would yield the reasonable maximum exposure is unknown, we can make a reasonable estimate of the dilution factor by taking the geometric mean of these two extreme values. The calculated value (~0.053) was rounded up to 0.055, which is the calculated dilution factor for the steel mill (see below).

---

<sup>2</sup> The term “dilution factor” is potentially confusing: the greater the dilution, the smaller the dilution factor. Thus, a dilution factor of one means that there is no dilution, a dilution factor of zero corresponds to infinite dilution. The 1997 draft TSD used the term differently.

## **Steel Mill**

The two EAFs at the reference steel mill have a combined nominal capacity of 150,000 tons (136,000 t) per year. The 7,500 t of potentially contaminated carbon steel scrap from the postulated decommissioning of the BWR power plant would equal 5.5% of the mill's annual capacity. The dilution factor for the steel mill operations is therefore 0.055.

## **Processing EAF Dust**

All of the contaminated baghouse dust is assumed to be processed at a high temperature pyrometallurgical metals recovery (HTMR) plant owned and operated by the Horsehead Resource Development Company (HRDC). The dilution factor for this scenario was calculated by comparing the processing capacities of the three HRDC facilities with the anticipated year-by-year releases from nuclear power plants in their respective service areas<sup>3</sup>. The largest dilution factor—leading to the greatest radiological impacts (see Note 2)—would occur at the HRDC facility in Rockwood, Tenn. in 2024, when 24,000 t of potentially contaminated carbon steel scrap would be released in the area comprising the Southeastern United States (NRC Region II) plus the states of Arkansas, Louisiana and Texas. As described in Appendix G, the melt-refining of this scrap would generate 380 t of baghouse dust. If all this dust were processed in the Rockwood facility, it would consume about 0.5% of the plant's annual capacity, yielding a dilution factor of 0.005 for this scenario. The processing of residually radioactive EAF dust at this facility is part of a hypothetical scenario constructed for the present analysis. The analysis should *not* be construed to predict that radioactively contaminated dust will, in fact, be processed at any specific facility.

## **Industrial Use of Mill Products**

It was assumed that the three industrial operations using mill products modeled in this analysis obtained all their materials from the reference mill. Thus, the materials are assigned the same dilution factor as the steel mill operations.

## **End Users**

Any one item could be made from a single heat which could contain a higher-than-average fraction of residually contaminated scrap. However, as discussed in Appendix G, because each heat is made up of scrap from a number of different sources, the probability that *all* of the scrap

---

<sup>3</sup> For the sake of simplicity, the carbon steel scrap from each nuclear power plant was assigned to the nearest HRDC facility, as determined by measuring point-to-point distances.

in any one heat would come from a nuclear facility is vanishingly small. The analysis presented in Section G.4.3 showed that the maximum likely fraction of contaminated scrap in any single heat during the course of one year is 50%; therefore, the dilution factor for the finished product in the end-user scenarios is 0.5.<sup>4</sup>

#### 5.4.2 Scrap Transport

The scrap transport worker is a truck driver who spends eight hours per day in the cab of a truck, carrying 20-t loads of scrap metal to the scrap processor and returning with an empty truck (or carrying other cargo). His only exposure would be to external radiation from the load of contaminated scrap.

#### 5.4.3 Scrap Processing Operations

Assessments were performed on a worker who spends six hours per day cutting the scrap, but spends a total of seven hours in canyons surrounded by scrap. He would also inhale and ingest dust which is assumed to have the same specific activity as the scrap.

#### 5.4.4 Steel Mill

Most mills that process scrap metal receive the scrap via truck or rail. Upon arrival at the mill, the scrap is unloaded, charged into an EAF and melted.<sup>5</sup>

### **Furnace Operations**

The scrap is unloaded by means of a large electromagnet and dumped into charging buckets that move the scrap to the furnace. The exposures of two workers performing representative tasks involved with furnace operations are assessed in the present analysis. One is the crane operator who transfers the charging bucket—he would be exposed to external radiation from the scrap in the bucket. The other is the furnace operator, who would be exposed to radiation from the scrap in the furnace while it is melting. They both would be exposed to fugitive furnace emissions which escape capture by the emission control system.

---

<sup>4</sup> This represents the 90th percentile value—there is at most a 10% probability that *any* of the 2,000 heats melted during one year would have a greater fraction of contaminated scrap.

<sup>5</sup> As noted in Section 5.1, the alternate scenario, in which scrap is first unloaded to a scrap pile at the mill, is not included in the analysis.

## **Interim Products**

Once the steel melts, it is poured onto a continuous caster. Torches cut the solidified steel into slabs as the metal runs down a set of rollers. Cooled slabs are stored, reheated and formed into products such as coils of sheet metal, or are sold in their raw form. The operator of the continuous caster would be exposed to external radiation from the molten steel in the tundish as well as from the continuous caster. He would also be exposed to fugitive furnace emissions.

## **Baghouse**

The baghouse contains rows of filters, suspended from the ceiling, that trap the particulate emissions from the melt-refining process. These bag-like filters are shaken at frequent intervals; the dust settles into collecting hoppers and is fed by a screw mechanism into a tanker trailer. Once filled to capacity, the trailer is transported away from the steel mill to a processing facility for recovery of commercially valuable components, primarily metals such as zinc, cadmium and lead, and for ultimate disposal.

Steel mill workers are occasionally assigned to spend a day repairing or changing the baghouse filters. Such a worker typically spends four to six hours<sup>6</sup> in the midst of the suspended filters in the dust-laden atmosphere of the baghouse, wearing a respirator equipped with a full facepiece. At a typical facility, this procedure is carried out an average of seven times per year. The analysis assumes that the same worker is assigned to this task every time. While performing such maintenance, the worker would be exposed to external radiation from the residual dust that is retained in the filters after they are emptied, as well as to the dust that has settled on the floor of the baghouse.

In addition, one worker typically spends about one hour per day monitoring the control mechanisms and performing maintenance that does not require entering the modules containing the filters. It is conservatively assumed that the same worker who maintains the filters would be assigned to this duty on days he was not inside the modules. The rest of the time, he would be assigned a variety of tasks in the steel mill. His external exposure rate during that time is

---

<sup>6</sup> Rest periods necessitated by work in a confined area and the need to don and remove protective clothing restrict the amount of time the worker can spend on this task.

assumed to be the same as that of the crane operator.<sup>7</sup> His internal exposure rate is assumed to be the average of workers inside a typical mill (see Appendix H).

The driver of the tanker truck transporting the dust off site would be exposed to external radiation from the dust in the truck. Since the reference facility operating at full capacity produces about 2,250 tons of dust per year, a truck carrying 25 tons of dust would make 90 trips per year. Since many EAF mills are more than a one-day drive away from the nearest processing facility, transporting the dust could occupy at least one driver full-time. He is assumed to return with an empty trailer.

### **Airborne Effluent Emissions**

Not all the fugitive furnace emissions are trapped in the baghouse. As noted on p. 5-9, some bypass the collection system, while others pass through the baghouse filters. In particular, radionuclides which form gases or volatile vapors would not be trapped by the filters. A family of subsistence farmers, who are postulated to live one km from the steel mill and who obtain a portion of their produce, meat and milk from their farm, would be exposed to these airborne effluent emissions. In most cases that are significant to the present analysis, the consumption of home-grown foods would constitute the primary exposure pathway.

### **Slag Disposal**

After the completion of the melt cycle, the EAF is tilted and the slag is poured into a ladle, which is moved by overhead crane to a slag yard outside the building. A worker at a typical facility spends about half his time on a platform on the edge of the slag yard and would be exposed to external radiation from the slag. Since the rest of his time is in the vicinity of the slag, he would be exposed to slag dust during the course of the day.

Since the slag pile is exposed to the elements, soluble components of the slag leach out of the matrix and percolate through the soil until they reach an underlying aquifer. (This process takes a number of years—see Section 6.4.1.) A nearby resident who gets his drinking water from a well that is downgradient from the slag pile might, at some time in the future, be exposed to contaminated groundwater.

---

<sup>7</sup> This worker was selected as having the median exposure rate to Co-60, one of the significant radionuclides in the present analysis.

#### 5.4.5 Processing EAF Dust

A worker at one of HRDC's HTMR plants who operates a front-end loader at the edge of a large pile of dust spends about four hours a day transporting dust from the piles to the conveyors. During this time he would be exposed to external radiation from the pile of dust. However, because the dust is assumed to contaminate the air and settle on accessible surfaces throughout the facility, he would be exposed to the inhalation and inadvertent ingestion of the dust throughout his workday.

#### 5.4.6 Use of Steel Mill Products

All products of the steel mill have industrial uses. The present analysis deals with two of these products—finished steel and slag—in addition to the reprocessing of baghouse dust, discussed in the preceding section.

##### **Slag**

As shown in Appendix I, slag is primarily used in road building, as fill or for soil conditioning. A worker employed in road construction would be exposed to external radiation from the slag in the roadbed as well as that in the cement pavement—he would also be exposed to contaminated slag dust.

##### **Steel**

Steel is used to make a virtually endless variety of finished products. The analysis considers the five categories of products which are listed below, along with an example of each category. These products also represent small, medium and large objects, as indicated below.

- Large home appliance (medium-sized object): double oven
- Automotive component (medium-sized object): engine block
- Large industrial equipment (large object): 8-ton metal-working lathe
- Cooking utensil (small object): frying pan
- Shipbuilding (large extended object): hull plate on naval support vessel

Only the oven and hull plate are made from carbon steel, however. The other three are made primarily of cast iron, which is produced by a different process. The radiation exposures of workers producing and assembling two of these products—engine blocks and industrial

lathes—are assessed in the present analysis. In each case, the workers would be exposed to external radiation from the iron, which is assumed to have the same dilution factor as the steel. The grinding operations on the lathe bed would also expose the lathe maker to the inhalation and ingestion of iron dust.

### **End Users of Finished Products**

The final group of exposed individuals are people who use the products listed in the previous section. One user of each of the five products, who was judged to be the RME individual for that product, is included in the analysis. A consumer would be exposed to external radiation from the steel in the kitchen range. A taxicab driver would be exposed to external radiation from the engine block, while a lathe operator would be exposed to radiation from the cast iron lathe bed. Another consumer cooking food in a cast iron frying pan would be exposed to external radiation from the cast iron, in addition to eating food which would be contaminated with residual radioactivity that has leached from the pan. Finally, a sailor on a naval support vessel would be exposed to external radiation from a hull plate next to his sleeping quarters.

## REFERENCES

- Eckerman, K. F., and J. C. Ryman. 1993. "External Exposure to Radionuclides in Air, Water, and Soil," Federal Guidance Report No. 12, EPA 402-R-93-081. U.S. Environmental Protection Agency, Washington, DC.
- International Atomic Energy Agency (IAEA). 1991. "Exemption Principles Applied to the Recycling and Reuse of Materials from Nuclear Facilities." Draft (unpublished).
- MicroShield, Ver. 4.2. Grove Engineering, Inc., Rockville, MD.
- O'Donnell, F. R., et al. 1978. "Potential Radiation Dose to Man from Recycle of Metals Reclaimed from a Decommissioned Nuclear Power Plant," NUREG/CR-0134. Oak Ridge National Laboratory, Oak Ridge, TN.
- S. Cohen & Associates (SCA). 1995. "Analysis of the Potential Recycling of Department of Energy Radioactive Scrap Metal." 4 vols. Prepared for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, DC.