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Evaluation of Radioactive Scrap Metal Recycling

Environmental Assessment Division
Argonne National Laboratory



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Evaluation of Radioactive Scrap Metal Recycling

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December 1995

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NOTATION

The following is a list of the acronyms, abbreviations, and units of measure used in this document.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AGR	advanced gas-cooled reactor
ALARA	as low as reasonably achievable
ANL	Argonne National Laboratory
ATSDR	Agency for Toxic Substances and Disease Registry
BOF	basic oxygen furnace
BRC	below regulatory concern
BWR	boiling-water reactor
CAAA	Clean Air Act Amendments
CANDU	Canadian deuterium-uranium (reactor)
CEC	Commission of the European Communities
DCF	dose conversion factor
DHHS	U.S. Department of Health and Human Services
DOE	U.S. Department of Energy
DRI	direct reduced iron
EAF	electric arc furnace
EC	European Economic Community
GCR	gas-cooled reactor
HTGR	high-temperature, gas-cooled reactor
HWR	heavy-water reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiation Protection
LGR	light-water-cooled, graphite-moderated reactor
LLW	low-level (radioactive) waste
LMFBR	liquid-metal, fast breeder reactor
LMGMR	liquid-metal, graphite moderated reactor
LMR	liquid-metal reactor
LWR	light-water reactor
NCRP	National Council on Radiation Protection and Measurements
NEA	Nucelar Energy Agency
NIOSH	National Institute for Occupational Safety and Health

NOAEL	no observed adverse effect level
NORM	naturally occurring radioactive materials
NSPS	New Source Performance Standards
OECD	Organization for Economic Cooperation and Development
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCI	pulverized coal injection
PEL	permissible exposure level
PHWR	pressurized heavy-water reactor
POM	polycyclic organic matter
PWR	pressurized-water reactor
RBMK	type of former Soviet Union reactor
REL	recommended exposure limit
RSM	radioactive scrap metal
SEG	Scientific Ecology Group
SIC	Standard Industrial Classification
SWU	separative work unit
TLL	threshold limit value
TWA	time-weighted average
U.S.A.	United States of America
USEPA	U.S. Environmental Protection Agency
USNRC	U.S. Nuclear Regulatory Commission
VVER	type of former Soviet Union reactor
ZGS	Zero Gradient Synchrotron

UNITS OF MEASURE

Bq	becquerel(s)
cm	centimeter(s)
cm^2	square centimeter(s)
cm^3	cubic centimeter(s)
dB	decibels
g	gram(s)
GeV	giga electron volt(s)
Gy	gray(s)
h	hour(s)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)

m^2	square meter(s)
m^3	cubic meter(s)
mm	millimeter(s)
MWe	megawatt(s)-electric
ppm	parts per million
Sv	sievert(s)
t	metric ton(s) (1,000 kg)
yr	year(s)

EVALUATION OF RADIOACTIVE SCRAP METAL RECYCLING

by

L.A. Nieves, S.Y. Chen, E.J. Kohout, B. Nabelssi, R.W. Tilbrook, and S.E. Wilson

ABSTRACT

This report evaluates the human health risks and environmental and sociopolitical impacts of options for recycling radioactive scrap metal (RSM) or disposing of and replacing it. Argonne National Laboratory (ANL) is assisting the U.S. Department of Energy (DOE), Office of Environmental Restoration and Waste Management, Oak Ridge Programs Division, in assessing the implications of RSM management alternatives. This study is intended to support the DOE contribution to a study of metal recycling being conducted by the Task Group on Recycling and Reuse of the Organization for Economic Cooperation and Development. The focus is on evaluating the justification for the practice of recycling RSM, and the case of iron and steel scrap is used as an example in assessing the impacts. To conduct the evaluation, a considerable set of data was compiled and developed. Much of this information is included in this document to provide a source book of information.

1 INTRODUCTION

1.1 SCOPE OF THE STUDY

Almost all of the previous literature related to RSM recycling has emphasized the radiological risks to human health that result from reusing RSM. To evaluate the justification for recycling as a practice, this study considers a much broader range of the detriments associated with the two RSM management alternatives: (1) recycling and (2) disposing of and replacing metal stocks. The scope of this study includes a quantitative assessment of both the radiological and nonradiological impacts on human health. Information on other risks from environmental and anthropogenic sources is provided as contextual background for considering RSM management alternatives. This study also considers radiological and nonradiological impacts on the environment that result from operational activities and process emissions. Major types of social and economic impacts are identified and evaluated in qualitative terms. The study does not develop estimates of the comparative costs of recycling versus disposal, which could also be considered when the justification for recycling is being evaluated.

1.2 OVERVIEW OF CONTENTS

The approach used in this evaluation is to develop a broad characterization of recycling process scenarios to determine the scope of impacts that must be considered. Impacts are presented first for recycling (Section 5) and then for the alternative of disposal and replacement (Section 6). The concept of alternative levels of regulatory control for RSM release for recycling, or "tiers," is incorporated into the analysis. The analytical framework employed to evaluate recycle alternatives is briefly described in Section 1.2. Section 2 summarizes the study findings, covering impacts both from RSM recycling process options and from the alternative of RSM disposal and metal replacement.

Partial worldwide RSM inventory estimates are presented in Section 3. While the spectrum of potential RSM sources is identified, comprehensive estimates of metal masses are only developed for nuclear power plants. Information for RSM from power plants is presented in the most detail because of the nature of the available data. Weapons facilities are likely to be significant sources of RSM, but quantities are very difficult to ascertain lacking specific data. The quantity of RSM available from weapons facilities and other sources is assumed to be at least equal to that available from nuclear power plants. This inventory indicates the quantities of metals by type (and the associated categories of contamination characteristics) that could be available for recycling. It also provides estimates of the possible timing of scrap flows.

Section 4 describes the international market context in which recycled RSM would have to be accepted and traded if it were released for unrestricted use. It provides information on metal production and market structure as background to considering potential impacts of RSM recycling. This evaluation covers international scrap flows in response to supply and demand factors and the near-term price and trade situation. Recent experiences relative to radioactive contamination of scrap and the industry response in the U.S.A. are also discussed.

Impacts of RSM recycling options are addressed in Section 5, which uses iron and steel scrap as an example because this segment makes up the largest portion of available scrap. As a basis for impact evaluation, a tiered release concept and associated exposure scenarios are defined. The discussion includes radiological impacts to metal workers and to the public, radiological impacts to industrial technologies identified as possibly being sensitive, and nonradiological impacts to workers from decontamination and smelting activities required for RSM recycling. Release levels for RSM are derived on the basis of worker and public exposure estimates for the release tiers. Although the focus is on health, environmental impacts of RSM recycling processes are also evaluated.

Section 6 summarizes the impacts of the alternative of not recycling the RSM, again focusing on iron and steel. This discussion addresses appropriate disposal of the contaminated metals and production of replacement metal supplies. For replacement of discarded RSM, the impacts on air, land, water, and energy resources, as well as on worker and public health, are presented for mining and refining. The impacts of producing coking coal for use in production of steel are also addressed.

Socioeconomic and political impacts of recycling are discussed in Section 7. A brief review is included of some crucial issues that must be addressed to facilitate recycling of RSM. An overview of the regulatory principles and processes for exempting RSM-containing products from regulatory control is presented first, followed by a discussion of the legal issues involving products liability that must be considered before RSM recycling is undertaken by commercial firms. Information on cross-cultural similarities and differences in perceptions of nuclear-related risks is presented, and results of an effort to ascertain the likely positions of key organizations in the recycling policy arena are reported. Finally, key factors and issues that are likely to affect public acceptance of RSM recycling are summarized.

2 SUMMARY AND CONCLUSIONS

Current and potential sources of radioactive scrap metal (RSM) include nuclear power plants, nuclear fuel cycle facilities, weapons production facilities, research and development reactors, high-energy accelerators, industrial sterilizer plants, industrial radiography equipment, medical facilities and equipment, and petroleum and phosphate rock extraction equipment. Millions of metric tons (t) of scrap iron and steel, stainless steel, and copper — as well as lesser quantities of aluminum, nickel, lead, and zirconium — are likely to become available in the future as these facilities are withdrawn from service.

The major alternatives for managing RSM are to either (1) develop a regulatory process for decontamination and recycling that will safeguard human health or (2) dispose of the RSM and replace the metal stocks. To date, relatively small quantities of RSM from various facilities have been recycled for public use, but thousands of tons have been recycled within the nuclear industry (Menon and Teunckens 1994; Hertzler et al. 1993). The magnitude of the potentially available supply, as well as the very low level of radioactivity in a major portion of it, warrant consideration of a broad range of end uses for this material.

This study evaluates recycling as a management alternative for radioactive steel scrap within the context of the system of radiological protection recommended by the International Commission on Radiological Protection (ICRP) (1991). Impacts of recycling are compared to those associated with disposing of and replacing the metal. The clear conclusions are that recycling is justified as a practice, that protection can be optimized through implementation of a tiered system of release criteria, and that individual dose can be controlled to acceptable levels.

2.1 ANALYTICAL APPROACH

Strategies for managing RSM must be evaluated within the context of principles for regulation of practices that result in radiation exposure of the public. The ICRP (1991) has recommended a system of radiological protection based on three general principles. The first is that before any practice involving increased radiation exposure is instituted, it must be justified as providing greater good than harm. To evaluate whether a practice does more good than harm the ICRP recommends that all detriments of the practice be considered, not just the radiological detriment. Second, radiation protection, including the cost of regulatory control, should be optimized. This involves keeping individual and population doses as low as reasonable achievable, given economic and social factors. It also involves equity considerations regarding the distribution of risk. Third, individual risks must be controlled at a sufficiently low level so as not to warrant regulatory concern.

Given these guidelines, this study evaluates the health risks, environmental impacts, and socioeconomic issues associated with the RSM management alternatives. Both radiological and nonradiological risks to human health are assessed, but the treatment of

radiological risks is more detailed because of the need to explore issues related to potential development of international standards for recycling. The assessment of health risks focuses on the public, including industrial workers. Illustrative examples are presented for iron and steel scrap because it constitutes a major portion of the potential RSM volume. The parameter, dose, and activity level values that are specific to steel in this report would need further investigation before the findings could be applied to the recycling of nonferrous metals. Environmental impacts are discussed in terms of the nature and relative magnitude of effects on environmental quality and resources. Socioeconomic issues related to recycling RSM are identified, and their implications for implementation of recycling are discussed.

For RSM recycling, a tiered system of release criteria for a wide range of end uses is evaluated because this approach has the advantage of matching RSM supply with demand while controlling public health risks at a very low level. Controlling health risks is accomplished by tailoring release levels to both the radiological characteristics of the scrap and its potential end uses. The tiered release concept includes options of unrestricted release of surface-contaminated metal in its existing form (e.g., machinery) for reuse or disposal, unrestricted recycle of ingots cast from RSM after melting in a controlled facility, prescribed initial use of RSM products, and controlled recycle in the nuclear industry.

The alternative to releasing RSM is to dispose of it in a low-level waste (LLW) disposal facility. This process requires cutting and packaging RSM for transportation and disposal and could also involve decontamination to reduce worker exposures and melting to reduce volume. Disposal would result in withdrawal of the RSM from world stocks of metal, major portions of which are normally recycled. At the margin, metal stocks are increased or replaced by metal newly produced from ore. Therefore, metal replacement activities are considered as contributing to the detriment associated with RSM disposal. These activities include mining of ore, ore enrichment or refining, metal smelting, casting and fabrication, and production of the energy required for these activities.

2.2 HEALTH RISKS

2.2.1 Radiological Health Risks

Radiological risks from either RSM recycling/reuse or disposal and replacement are very low. Estimates of radiological risks associated with 50,000 t of RSM under either alternative are summarized in Table 2.1. For illustrative purposes, the release levels for the tiers are derived on the basis of limiting the public dose to 10 μSv/yr (International Atomic Energy Agency [IAEA] 1988). On this basis, lifetime cancer fatality risks to individual members of the public, including industrial workers, from recycling 50,000 t of RSM would be less than 10^{-6}. For the RSM disposal alternative, radiological risks from exposure of the public as a result of RSM disposal are assumed not to exceed regulatory limits of 10^{-5}. Overall, the level of individual risk to the public is likely to be slightly lower for recycling than for disposal due to the greater stringency of the dose constraints. Individual risks to nuclear workers are subject to a regulatory limit of 10^{-3} for either recycling or disposal. For

TABLE 2.1 Health Risk Estimates for Radioactive Scrap Metal (Steel) Management Alternatives

Activity	Group Affected	Risk Type	Health Risk Estimate from One Year of Activity[a]	
			Recycle/Reuse	Disposal/Replacement
RSM transportation[b]	Public	Accident/fatalities Radiation/cancer	5×10^{-3} (collective) Negligible	5×10^{-3} (collective) Negligible
	Truck drivers	Radiation/cancer	1×10^{-5}	1×10^{-5}
RSM disposal (LLW)	Nuclear workers	Radiation/cancer	10^{-3} (regulatory limit[c])	10^{-3} (regulatory limit[c])
	Public	Radiation/cancer	5×10^{-5} (regulatory limit[c])	5×10^{-5} (regulatory limit[c])
RSM decontamination and preparation	Nuclear workers	Radiation/cancer Chemical/cancer	10^{-3} (regulatory limit[c]) 10^{-3} (regulatory limit[c])	NA
Controlled smelting	Nuclear workers	Radiation/cancer Chemical/cancer Accident/fatalities	10^{-3} (regulatory limit[c]) 10^{-3} (regulatory limit[c]) Unquantified[d]	NA
	Public	Radiation/cancer Chemical/cancer	Unquantified Unquantified	NA
Ingot transportation[b]	Truck drivers	Radiation/cancer	1×10^{-5}	NA
	Public	Accident/fatalities Radiation/cancer	5×10^{-3} (collective) Negligible	NA
Commercial smelting	Smelter workers	Radiation/cancer Chemical/cancer Accident/fatalities and injuries	10^{-7} to 10^{-6} (note c) 10^{-3} (regulatory limit[c]) 8×10^{0}	Unquantified 10^{-3} (regulatory limit[c]) 8×10^{0}
	Public	Radiation/cancer Chemical/cancer	3×10^{-8} (note c) 2×10^{-4}	Unquantified 2×10^{-4}
Steel end use	Public	Radiation/cancer	10^{-7} - 10^{-6} (note c)	NA
Iron ore mining and enrichment	Miners	Radiation/cancer Chemical/cancer Accident/fatalities	NA	5×10^{-5} to 3×10^{-3} 10^{-3} (regulatory limit[c]) 1×10^{-2}
	Public	Chemical/cancer	NA	Unquantified
Ore transportation	Public	Accident/fatalities	NA	1×10^{-3} to 4×10^{-2} (collective[e])
Coking coal production	Miners	Accident/fatalities	NA	2×10^{-3} to 3×10^{-2}
	Oven workers	Chemical/cancer	NA	1×10^{-2} to 6×10^{0}
	Public	Chemical/cancer	NA	1×10^{-3} to 7×10^{-2}
Coke transportation	Public	Accident/fatalities		1×10^{-3} to 4×10^{-2} (collective[e])

TABLE 2.1 (Cont.)

Activity	Group Affected	Risk Type	Health Risk Estimate from One Year of Activity[a]	
			Recycle/Reuse	Disposal/Replacement
Pig iron production (blast furnace)	Workers	Radiation/cancer Chemical/cancer Accident/fatalities and serious injuries	NA	Unquantified 10^{-3} (regulatory limit[c]) 7×10^{0}
	Public	Radiation/cancer Chemical/cancer	NA	Unquantified 2×10^{-4}

[a] Assumes 50,000 t of RSM or replacement steel. All risks are reported for the most exposed individual unless designated as collective. NA = not applicable.

[b] Assumes 100 km per round trip and 20 t per shipment.

[c] Maximum individual lifetime risk of cancer fatality resulting from one year of exposure at the maximum permissible concentration.

[d] Accident rates are likely to be substantially lower than in commercial facilities.

[e] Rail transport has the lowest rate and truck transport the highest.

replacement of disposed RSM, the upper range of risks to metal miners from natural occurring radioactivity, mainly radon (United Nations 1993), is about the same magnitude as the regulatory limits for nuclear workers.

On the basis of the radiological health impact analysis, several conclusions have been reached. Implementation of a tiered-release concept in such standards would provide flexibility in the release of radioactive scrap metals without sacrificing public protection. Release standards should be based on reasonable assumptions regarding key parameters. For example, radionuclide partitioning factor ranges for steel melting under various conditions are fairly well documented for a number of important nuclides. Also, a minimum level of likely RSM dilution in commercial smelters can be established based on current practices. In addition to the nuclide partitioning factors and metal dilution factor, several other sensitive parameters have been identified. These parameters include dust loading for smelter worker scenarios and the particulate surface emission rate for reuse scenarios; the corrosion rate of frying pans for the ingestion pathway scenario; and the radon emanation factor for radon parents in unrestricted reuse scenarios. These sensitive parameters deserve further investigation.

Different categories of release levels should be established for like groupings of radionuclides. Levels for such a radionuclide group should not be driven by a single nuclide or a few nuclides, such as Co-60. Rather, a separate (and more restricted) release level can be assigned for Co-60. Although the constraining individual doses are generally those for commercial smelter workers, an RSM throughput of 50,000 t results in collective doses for the public that may cause concern (particularly for Co-60) with regard to the criterion of 1 person-Sv for an annual practice.

The nuclide category of radon parents was analyzed for the unrestricted reuse option with the results indicating that the activity levels must be quite low to meet the dose constraint of 10 μSv/yr. Determining appropriate release levels is complicated by the fact that radon buildup from decay product ingrowth results in a maximum dose several years following release.

2.2.2 Nonradiological Health Risks

Both the recycle and the disposal and replacement alternatives involve health risks from worker and public exposures to chemicals that are carcinogenic or toxic, as well as from workplace and transportation accidents. Of these two major types of risks, the fatality risks to the public and workers from accidents are higher and much more immediate than the risks from chemical (or radiation) exposure. Health risks for individuals from chemical exposures and accidents are summarized in Table 2.1.

2.2.2.1 Accidents

Accident risks from transportation and smelting operations apply to both RSM recycling and replacement. On the basis of accident fatality rates for combination trucks on interstate highways in the U.S.A. (Saricks and Kvitek 1991), about 1×10^{-2} fatalities would be expected for recycling 50,000 t (assuming two 100-km transport segments). Disposal would require shipment of RSM to the LLW disposal site, with a risk of 5×10^{-3} fatalities for 100 km transport of 50,000 t. In addition, both iron ore and coking coal would require transportation to the steel foundry. For 50,000 t, this would require two segments of bulk transport with a combined risk of 3×10^{-3} to 9×10^{-2} fatalities on the basis of data for coal (U.S. Department of Energy [DOE] 1988). The total risk estimate for disposal/replacement transportation is 7×10^{-3} to 9×10^{-2}.

Replacement of RSM would involve accident risks for workers involved in metal and coal mining activities. On the basis of the 1990 fatality rate for iron miners in the U.S.A. (U.S. Department of Labor 1991), to replace 50,000 t of RSM, about 10^{-2} worker fatalities would be expected. For coal mining, replacing 50,000 t of RSM would incur additional fatality risks for coal miners of 2×10^{-3} to 3×10^{-2} (based on DOE 1988).

The annual rate of fatalities and major injuries from blast furnace operation (U.S. Department of Labor 1989) is equivalent to 7 fatalities or disabling injuries from pig iron production to replace 50,000 t of RSM. The fatality and serious injury rate for iron and steel foundries is also relatively high (U.S. Department of Labor 1989), resulting in an additional risk of 8 fatalities or disabling injuries for production of 50,000 t of replacement steel or RSM melting at a commercial smelter. This results in a total risk from steel production processes of about 15 serious injuries or fatalities. Steel replacement also involves accident risks in coking coal production, but these accidents are not quantified in this study.

2.2.2.2 Chemical Exposures

Chemical exposures for workers and the public from smelting operations are likely to be similar for the RSM recycling and RSM replacement alternatives. However, replacement would also result in worker and public exposure to chemicals from metal ore and coal mining, coking coal production, and pig iron production. Although impacts to workers and the public are not quantified for releases of toxic chemicals to air, water, and soil during mining and releases from tailings piles and mine wastes, the released substances are associated with cancer and a variety of other serious illnesses.

As part of the decontamination and recycle process, RSM may be melted in a controlled melt facility. As a result of radiological exposure controls, chemical exposures of radiation workers and the public from these activities are likely to be very low. After release for unrestricted recycling, RSM could be remelted in a commercial smelter, resulting in chemical exposures to commercial metal workers and to the downwind population. The resulting health impacts would be similar to those that occur from routine commercial recycling of scrap in metal production. For the RSM replacement alternative, similar types of chemical exposures would occur from both pig iron production (blast furnace) and steel smelting (basic oxygen process) required for finished steel.

RSM replacement also requires the production of coke from coal for producing iron in blast furnaces as an input to steel production. Emissions from coking ovens have been implicated in both cancers and chronic respiratory ailments. For replacement of 50,000 t of RSM, the cancer fatality risk is 1×10^{-2} to 6×10^{0} for workers, depending on emission controls, and 1×10^{-3} to 7×10^{-2} for the public (based on Dong et al. 1988).

The assumptions used to calculate intake of air emissions from smelting are conservative overestimates for the general population. Of the contaminants of concern, five (arsenic, cadmium, chromium VI, lead, and nickel) are classified as known or probable human carcinogens via inhalation. The carcinogenic risk of lead cannot be calculated at this time due to lack of necessary data. The calculated inhalation carcinogenic risks associated with the upper estimate of steel production emissions range from 7×10^{-7} for cadmium to 2×10^{-4} for chromium, with a sum risk of 2×10^{-4}.

Although air emissions are the main source of public exposure from smelting, workers may also be exposed to dust in the workplace atmosphere and from slag handling. The key contaminants in blast furnace slag are arsenic and mercury, and those in steel slag are arsenic, fluoride, and molybdenum. The key contaminants for dust/sludge solids from air pollution control devices in steel furnaces are cadmium, mercury, molybdenum, and selenium; contaminants associated with blast furnaces are arsenic, chromium, fluoride, and selenium.

Smelting residuals could also have impacts on the public, depending on waste disposal practices. The likelihood of adverse impacts to groundwater from these contaminants is low where certain mitigating conditions exist. The likelihood of adverse impacts to surface water from slag is also generally low because of the small fraction of erodible-sized solids ($\leq$0.1 mm), and the likelihood can be further reduced by runon/runoff controls. For

dust/sludge solids, the particle size (<0.02 to 2 mm) results in susceptibility to air transport (U.S. Environmental Protection Agency [USEPA] 1990). Thus, impacts could result from uncontrolled placement of this waste (e.g., depending on a facility's proximity to a drinking water source).

For human exposures to airborne particulates, the key contaminants for slag are arsenic, chromium, manganese, and nickel; those for dust/sludge are arsenic, cadmium, and chromium. In general, the large size of slag fragments (most are >100 μm in diameter) limits the potential for downwind exposures (USEPA 1990). Thus, public exposures to slag particles are less likely than are exposures to dust/sludge particles. The location of receptors relative to a facility is the primary factor in determining the potential significance of exposures.

2.2.3 Relative Magnitude of Health Risks

Potential health risks to workers and the general public are associated with both the recycle/reuse and the disposal and replacement management alternatives for RSM. These alternatives involve health risks from exposures to radiation and toxic elements, as well as from industrial and transportation accidents. For both alternatives, the risks to workers from workplace accidents and to the public from transportation accidents are greater in magnitude than the risks from radioactive materials or chemicals.

Regulatory constraints on radiation exposure of workers and the general public would hold risks to very low levels under either alternative. Releasing RSM that met the derived activity levels for the modified-conservative unrestricted reuse or recycle, or prescribed initial use cases would result in a lifetime cancer fatality risk level for an individual of the general public of 10^{-7} to 10^{-6} from annual exposure (based on Safety Series No. 89 [IAEA 1988]). Risks to commercial metal workers would be of a similar magnitude and could potentially be reduced further by use of protective measures. The total collective risk level would be 10^{-2} to 10^{-1} cancer fatalities from an annual recycling practice. For the replacement alternative, some miners could be exposed to naturally occurring radioactivity that could approach the level of the regulatory limit for nuclear workers. Such exposures would be more likely for nonferrous metals, such as copper, than for iron mining.

The nonradiological health risks would be greater overall than the radiological risks for either alternative. The highest health risk levels would be those for fatalities or disabling injuries from workplace accidents. For the recycling alternative, these risks would apply to decontamination activities, including controlled melting, and to commercial smelting. The risks would be at least twice as high for the disposal and replacement option because it would involve iron mining, coal mining, coke production, and blast furnace operation for pig iron production in addition to steel smelting. Transportation accident fatality risks would be on the order of 10^{-3} for each 100 km that the RSM or replacement materials were shipped. Transportation requirements and, therefore, risks would likely be higher for disposal/replacement than for recycling. Chemical risks to commercial metal workers and the public from melting RSM would be similar in nature to, but less than, those generated by smelting metal from ore.

For the portion of RSM that comprises the relatively large quantity of suspect, but probably nonradioactive scrap, both the radiological and nonradiological risks to the public and metal workers would be lower for recycling than for replacement because most of the radionuclides and contaminants that naturally occur in ore would have been removed in the original smelting of the RSM. Overall, the recycle option involves controlled risks borne by radiation workers and small increases in risks to commercial metal workers and the public. The disposal and replacement option, on the other hand, involves controlled risks to radiation workers and substantial increases in relatively uncontrolled risks to miners and the public. Health risks for the disposal/replacement alternative would be at least twice the level of risks for the RSM recycling alternative.

2.3 ENVIRONMENTAL IMPACTS

Impacts to air, land, water, and energy resources from RSM recycle or disposal and replacement are difficult to quantify; a qualitative discussion is presented below. The major types of environmental effects likely to be associated with each alternative are summarized in Table 2.2.

2.3.1 Impacts on Land Resources

Recycling RSM would produce relatively minor impacts to land use. Less than 10% of the inputs to controlled melting of RSM would require disposal as LLW. The disposal and replacement option, in contrast, is likely to substantially impact land use because of the requirements for RSM disposal area, replacement iron ore mining, and coal mining for coke production. Lands that are disturbed or contaminated by toxic metals in this process are generally not reclaimed, even in countries with applicable environmental legislation (Johnson and Paone 1982). In addition, huge piles of mining wastes and ore tailings may be left exposed, from which toxic chemicals would continue to be leached. Quantities of mining wastes are commonly 100 or more times the quantity of ore extracted.

2.3.2 Impacts on Water Quality

To the extent that aggressive decontamination efforts would be employed, RSM recycling could result in some effluent releases to nearby surface water bodies. These effluents would be treated to meet local standards for release and would have negligible impacts on water quality. Metal replacement activities, however, are likely to cause adverse impacts to both plants and animals from acidification and sedimentation of surface waters. Leaching of toxic and radioactive chemicals to both surface water and groundwater is also a problem, especially in the case of nonferrous metals. The acidity of mine drainage water promotes leaching of heavy metals from soils, transferring them to streams and rivers where they may be concentrated in some parts of the food chain. These problems tend to persist long after mine operations have ceased.

TABLE 2.2 Environmental Impacts of Activities Associated with Radioactive Scrap Metal (Steel) Management Alternatives

Resource Affected	Impacts from RSM (Steel) Management Alternatives	
	Recycle/Reuse	Dispose and Replace
Land use	Some LLW involved, but no new sites required	Substantial expansion of LLW disposal site capacity required Increased land use for mining Increased land disruption and damage from mining wastes Accumulation of heavy metals in soils as a result of mining and refining
Water quality	Controlled release of decontamination effluents	Acidification of surface water flowing from mining sites Increased leaching of heavy metals from soils and mining wastes into surface and groundwater Leaching of radioactive elements from mining wastes into surface water and groundwater Increased sedimentation of streams and rivers Release of heavy metals from smelting into surface water
Air quality	Emissions of SO_2 from smelting	Greater emissions of SO_2 from smelting
	Emissions of toxic chemicals and radioactive materials from smelting	Emissions of toxic chemicals from mining operations, waste piles, smelting, and coke production Emissions of naturally occurring radioactive materials from mining and smelting
Mineral resources	LLW disposal may be needed for some slag (instead of being usable)	Substantial metal ore quantities required Substantial coal quantities required for coke inputs to iron production
Energy resources	Some energy use for smelting scrap	Much higher energy use in refining ores and in producing coke

2.3.3 Impacts on Air Quality

Recycling of RSM involves three major types of activities that could generate emissions that would degrade air quality: decontamination, melting in a controlled smelter, and remelting at a commercial mill. The presence of radioactivity and hazardous chemicals requires efficient emission-control technology for exhaust air in decontamination and melting activities, so emissions from these activities are likely to be negligible. Controls would likely be less stringent on emissions from commercial steel mills where the RSM would be remelted and some air quality impacts could occur. However, emissions from recycling are less than those from primary metal smelting because many impurities have previously been removed and less energy is generally required for recycling. For the disposal and replacement option, substantial impacts to air quality would result from metal replacement activities. Most air emissions generated in metal production come from the ore enrichment and refining processes, and, in the case of steel, from coke production.

2.3.4 Impacts on Energy Resources

The energy requirement for steel replacement is likely to be two to three times greater than that for the RSM recycling alternative. In metal production generally, most of the required energy inputs are applied in the refining stage. The relative energy savings from using copper or aluminum scrap are even greater than for steel scrap. Although some decontamination techniques such as electropolishing are relatively energy intensive, energy use is still likely to be less for recycling RSM than for replacement.

2.3.5 Relative Magnitude of Environmental Impacts

Major differences exist in the environmental impacts associated with the recycling and disposal alternatives. In general, recycling RSM would have less of an environmental impact and would require a smaller commitment of natural resources. The disposal and replacement alternative would require substantial land area for RSM disposal, and metal replacement processes would result in major disruption of land for mining and in contamination of land and water with toxic elements. Radionuclides and heavy metals would be released to air and water during refining processes, and much greater energy resources would be required than is the case for recycling scrap metal. For steel, the impacts would be substantially larger for replacement than for recycling in virtually all categories.

Producing 1 t of steel from raw materials requires more than 2 t of iron ore and 0.5 t of coke, and mining the ore and coal produces numerous tons of wastes. Substantial land areas are disturbed or contaminated by toxic metals in this process, and these areas are usually not reclaimed. Both toxic and radioactive elements are released to surface waters, and rivers can be damaged by sedimentation as a result of mining and refining processes for metal replacement. Water quality impacts from RSM recycling, in contrast, are likely to be kept to minimal levels by regulatory controls and good operating practices.

Only in the air emissions category would impacts of recycling approach those of disposal and replacement. The nature of emissions from smelting would be similar in both cases, but quantities of hazardous emissions from melting scrap are likely to be smaller because many impurities would have previously been removed. In addition, recycling of scrap steel would require two to three times less energy, thus reducing secondary impacts from fuel combustion. For all the processes required, air quality impacts would likely to be somewhat higher from metal replacement than from recycling.

2.4 SOCIOECONOMIC ISSUES AND IMPACTS

Several issues are relevant to the choice between the RSM management alternatives of recycle/reuse and disposal/replacement. Such issues include LLW disposal site availability, public acceptance of recycling, potential impacts of either alternative on metal markets, effect of radioactivity in the metal supply on sensitive industrial uses of metal, international equity issues, and need for an international regulatory standard for RSM recycling.

2.4.1 Disposal Capacity

Disposal of the potential international RSM inventory as LLW would require disposal capacity of approximately 5×10^6 m^3 (assuming uncompacted metal with 30% void space). This contrasts with current commercial LLW disposal rates for all types of materials of 3×10^5 m^3/yr in the U.S.A. (Oak Ridge National Laboratory 1992). Although new LLW disposal facilities are anticipated to become available, disposal cost in the U.S.A. are likely to continue to increase, and access to disposal sites is likely to be limited on the basis of the geographic location of the waste generator. In a number of European countries, LLW disposal facilities currently are available or under construction, but in general new facilities will be required to accommodate wastes generated during nuclear facility decommissioning (Nuclear Energy Agency 1991). There are major political constraints on availability of disposal capacity because siting and operation of LLW disposal facilities is a significant issue in several countries.

2.4.2 Public Acceptability of Recycling

The public may see the choice between recycling or disposing of RSM as an issue of having a metal supply that is clean versus having one that is radioactive, although the issue is not actually that clear-cut. Iron and steel, for instance, generally contain small amounts of naturally occurring radioactive materials that originate with the ore deposits or with the coal used in coke production. Measured background activities of uranium and thorium in steel are on the order of 10-5 to 10-4 Bq/g (Knoll 1979). In addition to naturally occurring activity, there are several other sources of radioactivity in iron and steel. For example, traces of Co-60 from measuring devices used in smelting are commonly found in steel, and reports are increasingly frequent of the discovery of metal that has been accidentally contaminated

by the inclusion of sealed radiation sources with melted scrap or for which the activity source is unknown.

Radioactive materials are currently used by the public virtually throughout the world, with varying degrees of public recognition of the associated risks. Radioactivity is incorporated intentionally, for its beneficial properties, in a variety of medical and household products and in personal items. It also occurs naturally in some products and is an unintended by-product of beneficial functions of others. Public perceptions of risk related to use of these products are influenced by product benefits, product familiarity, and the extent to which radioactive aspects of the product are publicized. RSM recycling differs from virtually all existing situations in which radioactivity is incorporated in consumer products because it does not provide a direct benefit. Instead, the main benefit of recycling RSM is the avoidance of environmental and health impacts from replacing the metal if it is not recycled.

2.4.3 Metal Market Impacts

On an annual basis, the estimated total worldwide RSM inventory could produce recycling flows of 5×10^5 t/yr of iron and steel, 1×10^5 t/yr of copper, and 4×10^4 t/yr of stainless steel over the period from 2010 to 2043. Increasing scrap metal supply by recycling RSM is expected to create downward pressure on scrap prices. The magnitude of the effect will depend on the relative size of the RSM flow and on the demand situation. Comparison of the potential annual RSM flow with measures of metal demand in regional markets indicates that RSM is likely to constitute a very small portion of scrap imports or of annual variation in scrap consumption in these markets. As a result, price impacts are expected to be small. The one exception is copper because the RSM quantities are sufficient to depress prices somewhat in some regional markets.

2.4.4 Impact Distribution

The distribution of impacts from the RSM management alternatives depends on the locations of RSM processing and disposal facilities and the locations of mining and metal production activities. In general, the inventory of RSM is greatest in relatively industrialized countries, and RSM is likely to be processed for recycling or to be disposed of in its region of origin. Risks from these activities are expected to be controlled, and no major risk shifting among regions is involved. Nor is risk shifting likely from product trade, even though metal product and scrap metal trade flows tend to be from more to less industrialized countries. If RSM was released only when it presented negligible public risk, these net trade flows would not represent a risk shifting of any significance. Establishment of an international standard for radioactivity in metals would provide a safeguard against transfer of risk among countries.

The major potential for impact shifting arises in the case of RSM disposal and replacement. Much of the world's ore production and refining occurs in less developed

countries and in countries that do not have strong systems for environmental and health protection. The distribution of raw material production among countries and the substantial health and environmental impacts of metal production create the potential for significant impacts in less developed countries if the option of RSM disposal and replacement is implemented.

2.4.5 Regulatory Issues

Recycling RSM is currently impeded by the lack of an accepted international standard for unrestricted release of this material. Some European countries have developed release standards, but contaminated metals are generally evaluated and released on a project-specific basis. The U.S.A. currently has a surface contamination standard for material release, Regulatory Guide 1.86 (U.S. Nuclear Regulatory Commission [USNRC] 1974) but none for volumetric activity. Development of worldwide RSM recycling will require further effort to determine appropriate activity levels to ensure protection of public health under possible conditions of exposure. A single set of international standards is needed to guide the unrestricted release of RSM because the international trade in scrap metals and metal products is so extensive. Differing national release standards will have adverse international trade ramifications.

2.4.6 Relative Magnitude of Socioeconomic Impacts

The availability and cost of LLW disposal site capacity is one of the most critical socioeconomic issues related to the RSM alternatives. If the RSM were disposed of as LLW, it would require greater LLW disposal site capacity than is currently available or planned, with all of the attendant problems of site development. In contrast, recycling of RSM would require much less LLW disposal site capacity to accommodate the residuals from decontamination procedures.

Metal market impacts from either alternative are likely to be minimal because RSM would represent only a small proportion of total metal production and metal scrap. However, some price effects could occur in regional markets for some metals.

RSM recycling and disposal activities are likely to take place in the countries in which the RSM sources are located. Metal replacement activities, especially mining, will occur in the locations where metal deposits are actively mined. Many of these mines are in less developed countries, which also tend to have less stringent health and environmental regulations and enforcement than the industrialized countries. As a result, RSM disposal and replacement has the potential for shifting the risks of RSM management to countries other than those generating significant quantities of RSM.

The issue of possible impacts on sensitive technologies from radioactivity in the metal supply has been found to have minimal impacts. This issue has to be, and has been,

dealt with regardless of whether RSM is recycled because many types of finished metal contain low levels of radioactivity.

Public acceptability of the concept of recycling materials with traces of radioactivity may be problematic because of the stigma associated with the nuclear industry in most industrialized countries. At the same time, RSM recycling has been carried out successfully in small quantities in a number of countries, and products containing low levels of added or naturally occurring radioactivity are widely used. The risks and impacts of metal replacement activities receive relatively less attention than radiological risks in most countries, even though they are substantially greater and more immediate. Acceptability of RSM recycling may depend on dissemination of information regarding the trade-offs and development of an international standard for material release as well as the regulatory infrastructure needed to implement that standard.

2.5 CONCLUSIONS

This study assessed and compared the impacts of RSM recycling to those of disposal and replacement within the context of the system of radiological protection. The findings indicate that recycling is justified as a practice. This is based on the finding that the health and environmental detriments associated with recycling are less than those of not recycling. Second, radiological protection for the practice of recycling can be optimized through implementing a tiered system of release criteria for materials suitable for unrestricted recycling, and use of other low-level contaminated materials within controlled environments. Third, such a system can be implemented while controlling individual and population doses to levels recommended by international agencies.

The health and environmental impacts and the socioeconomic issues associated with the two RSM management alternatives are compared in Table 2.3. Overall, recycling of RSM is likely to result in fewer impacts than disposing of and replacing it. The health and environmental impacts of recycling are clearly lower, in that health risks of recycling are almost half those for disposal/replacement and environmental impacts are orders of magnitude lower. The comparison of socioeconomic impacts is less clear. RSM disposal will be very costly and will adversely impact availability of low-level waste disposal capacity for materials that are impractical or infeasible to recycle. On the other hand, some public opposition to RSM recycling is likely, regardless of how low the risks may be. The extent of public acceptance of recycling is likely to be affected by the quality of the regulatory process and the provision of information regarding comparative risks of the RSM management alternatives.

2.6 REMAINING ISSUES

Several issues that merit attention were outside of the study scope or have not been fully addressed. One of these is the issue of nuclear worker exposure from activities required for recycling, to the extent that these are above and beyond requirements for disposal.

TABLE 2.3 Comparison of Impacts from the Radioactive Scrap Metal Management Alternatives

Impact Categories	Impacts from RSM (Steel) Management Alternatives	
	Recycle/Reuse	Dispose and Replace
Human Health Effect Risk[a]		
Radiological risk	10^{-7} to 10^{-6} fatal cancer risk to metal workers and public; 10^{-2} to 10^{-1} population risk per year of practice	Potential elevated cancer risk to miners
Nonradiological risks		
Accidents (work place)	About 7 fatalities or serious injuries to workers	About 15 fatalities or serious injuries to workers
Accidents (transportation)	10^{-2} collective fatality risk to workers and public	10^{-2} collective fatality risk to workers and public
Chemical exposure from smelting	10^{-3} fatal cancer risk to workers; 10^{-4} to public	10^{-3} fatal cancer risk to workers; 10^{-4} to public
Chemical exposure from coke production	None	1 fatal cancer risk to workers; 10^{-2} to public
Environmental Quality and Resource Use		
Land disturbance	Minimal	Substantial
Water quality degradation	Minimal	Substantial
Air quality degradation	Moderate	Moderate
Mineral resource requirement	Minimal	Substantial
Energy requirement	Moderate	Substantial
Socioeconomic Issues		
LLW site capacity	Minimal	Substantial
Public acceptability	Varies among countries; some opposition likely	Generally accepted except for local concerns
Metal market impacts	Minimal	Minimal
Risk distribution	Risk largely borne in country generating RSM	Risk largely shifted to less developed countries
Industrial applications	Minimal	None

[a] Risk estimates represent maximum individual lifetime risk associated with a 50,000-t throughput.

Relevant activities include metal surveying, sorting, decontamination, and controlled melting. Individual dose from these activities would be constrained by regulation; it is the population dose that could differ substantially for nuclear workers between the two alternatives. These differences have not be addressed in the literature to date.

A second issue involves the survey requirements for certification for release of metals that are not first melted. Both worker dose and survey cost may limit the feasibility of certifying objects for release for reuse. This study did not address issues of implementation; these remain for further evaluation.

Developing appropriate activity levels for unrestricted release of low-level contaminated materials requires an assessment of both the probabilities associated with various degrees of public exposure and the uncertainties regarding data and models for exposure parameters. This study includes extensive sensitivity analysis (discussed in Appendix C) to identify key parameters of the exposure models and it employs more realistic values for these parameters than most previous studies. There is still, however, considerable uncertainty regarding factors such as RSM dilution, melt partitioning, and surface contaminant transfer rates. Standard practice is to employ conservative assumptions in situations of uncertainty. In the case of RSM, the resulting high degree of public protection from exposure would be achieved with a disproportionately high resource commitment. Thus, further research, including collection of operational data, is recommended to reduce uncertainty regarding key exposure parameters.

The major open issue pertaining to recycling is that of public acceptability. There is evidence of public acceptance of many technologies that result in low levels of public exposure to ionizing radiation, but there is also evidence of a public hypersensitivity to issues and exposures related to the nuclear industry. An informal survey found a willingness on the part of industry and broad-focus environmental organizations to consider all aspects of the RSM management alternatives, so long as health and safety issues were not compromised. Public acceptance of RSM recycling will require documentation of public, including worker, safety; public education regarding the trade-offs between radiological detriment and other types of health and environmental detriments, involvement of a broad range of contaminated scrap generators, and a trustworthy system for certifying RSM contamination levels at the point of release.

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3 RADIOACTIVE SCRAP METAL INVENTORY

3.1 INTRODUCTION

This section presents estimates of the quantities of radioactive scrap metal (RSM) that could potentially be recycled from the major sources of RSM: the nuclear power industry, the weapons industry, and the petroleum and phosphorous extraction industries. More information is available for nuclear power plants than for the other two sources, and so the estimates rely heavily on nuclear power plant data. The discussion includes estimates of metal mass and information on metal type, nature of the radioactivity, and the timing and regional location of the potential material flows. Appendix A provides details on the method used to estimate the masses of RSM from nuclear power plants.

Section 3.2 identifies and defines the categories of degrees of radioactive contamination used in this report and discusses the suitability of each category for recycling. Section 3.3 examines the basic assumptions underlying the estimates of metal mass, and Section 3.4 identifies and briefly discusses the significant sources of RSM. The estimates of RSM from the nuclear power industry were developed from a detailed database on power reactors (Appendix A). The estimates of metal mass from the oil and phosphorous extraction industries were derived from a published report on those industries. Defense industry information was very hard to obtain, so that portion of the estimate was taken to be a factor of the estimate for the nuclear power industry.

3.2 DEGREES OF CONTAMINATION

Radioactive scrap can be classified by the anticipated level of radioactivity (activity level), which depends on facility design, operating history, maintenance, decay time, and decommissioning strategy. For this inventory, the metal scrap has been divided into the four general categories defined in Table 3.1: (1) suspect radioactive, (2) surface-contaminated — removable, (3) surface-contaminated — fixed, and (4) activated.

Because necessary data are largely not available, allocation of metal masses to these categories is based on component function in source plant operations rather than on activity levels. For a specific plant, the amounts of metals in the various activity-level classifications depend on such factors as facility design, operating history, and length of time since shutdown. Examples of assignment of components to the four general activity categories are as follows:

- Suspect Radioactive
  - Pressurized-water reactor (PWR) feedwater lines;
  - PWR steam lines and turbines;

TABLE 3.1 Activity Categories of Scrap Metal

Category	Description
Suspect Radioactive	This category consists of components with no significant surface contamination or activation. These components generally come from systems that are not associated with the reactor fuel or primary coolant systems. Examples include the cooling water system and the electrical generating and transmission systems. In some cases, health physics surveys will be required to confirm whether a specific component or system from a specific facility is nonradioactive. In most of the cases in which contamination is found, surface decontamination should be sufficient to produce a nonradioactive product.
Surface-Contaminated — Removable	This category consists of components that may have significant levels of surface contamination that can be removed to a level permitting unrestricted use. Extensive decontamination may be required for some components. These metals come from buildings and systems that are, or could be, exposed to primary coolant or fuel during normal operations or during any leaks or spills. The resulting surface contamination is due to fission or activation products in the coolant or released gases. Such items include the reactor building crane and containment building liner. This group includes system components with tritium impregnation caused by hydrogen diffusion.
Surface-Contaminated — Fixed	This category consists of components with significant levels of surface contamination that penetrates or is bound to the metal. There may also be some metal activation. Decontamination sufficient to permit unrestricted use is unlikely.
Activated	This category consists of components with significant levels of activation. These materials may also have high levels of surface contamination. Decontamination may be performed to reduce worker radiation exposure, but decontamination alone is not expected to be sufficient to produce material free of significant activity.

- Reactor building reinforcing bars (rebar) (>95% in this category);
- Cooling towers, mechanical systems, and piping;
- Water-cleaning systems;
- Diesel generator systems;
- Switchyard equipment, transformers, electrical busses, batteries, etc.;
- Control and instrumentation cables (>95% in this category); and
- Building metal in turbine and other auxiliary buildings.

- Surface-Contaminated — Removable
  - Reactor containment-building crane;
  - Reactor containment-building liner;
  - Reactor building structural steel;
  - Crane for fuel handling;
  - Fuel-handling machine;
  - Fuel storage pool liner and equipment;
  - PWR primary loop lines, outside reactor cavity;
  - PWR primary pumps and valves;
  - Boiling-water reactor (BWR) steam lines and turbines; and
  - PWR steam generators and accumulators (parts).

- Surface-Contaminated — Fixed[1]
  - Liquid radwaste systems (some components);
  - Fuel reprocessing system components; and
  - PWR steam generators and accumulators (parts).

- Activated[2]
  - Reactor pressure vessel;
  - Reactor pressure vessel cover and internals;
  - Control rod drive lines;
  - Boron poison lines and similar components within reactor cavity;
  - Instrumentation and control cables (small fraction of total); and
  - Reactor building structural steel proximate to reactor pressure vessel (small fraction of total).

Most of the activated radioactive components identified above are in areas of the plant not conveniently accessible for early decontamination and processing. By the time these items are ready for disposal, activities in most of the lower-activity metal will have decayed to a level appropriate for reclassification as clean or cleanable scrap.

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[1] For the case of nuclear power plants, this category includes only a small fraction of the contaminated scrap.

[2] Decontamination may be performed to reduce worker radiation exposure, but decontamination alone is not expected to be sufficient to produce material free of significant activity.

3.3 BASIC ASSUMPTIONS

3.3.1 End-of-Life for Power Plants

Nuclear power plants have useful lives of approximately 40 years. When the useful lives of existing plants expire, large quantities of RSM will become available for recycling as plants are dismantled. A number of assumptions can be made concerning the extent to which nuclear facilities are dismantled. For example, a phased approach can be used in which only limited removal of material occurs before the appropriate portions of a site are secured for a scheduled number of years in order to allow radioactivity to decay before dismantlement is resumed. On the other hand, a site can be decontaminated and reclaimed as rapidly as regulations allow, to the point at which the site, including all remaining structures, is released for unrestricted use. At the extreme end is the "greenfield" case, in which all hardware, radioactivity, and structures have been removed, and the site is returned to landscape.

The U.S. Nuclear Regulatory Commission (USNRC 1988) has defined three classifications for decommissioning of nuclear facilities:

- DECON: ". . .equipment, structures and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations."

- SAFSTOR: ". . .the nuclear facility is placed and maintained in such condition that the nuclear facility can be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use."

- ENTOMB: ". . .radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombment structure is appropriately maintained, and continued surveillance is carried out until the radioactivity decays to a level permitting unrestricted release." As noted on p. 170 of the 1991 Integrated Data Base report (Oak Ridge National Laboratory [ORNL] 1991), this alternative would be allowable for facilities contaminated with relatively short-lived nuclides that would decay to levels permitting unrestricted use within a period on the order of 100 years.

Essentially, SAFSTOR and ENTOMB are options for deferring the eventual implementation of the requirements of DECON.

For the purposes of this report, the assumption is made that the site is decontaminated and reclaimed to the point at which it is released for unrestricted use in "greenfield" condition. At that point, all radioactive scrap will have been removed.

3.3.2 Radioactive Decay

Because of the process of radioactive decay, the quantity of radioactivity decreases with time after plant shutdown. Decommissioning and demolition of a plant may be deliberately delayed or conducted in time-separated stages in order to decrease the total dose to workers. Because of licensing requirements that radioactive systems be maintained in a safe condition, a plant cannot be decommissioned until several years after shutdown. For example, the primary coolant circuit and all of its supporting systems must be maintained in their active conditions while fuel is still in the core, and the fuel storage pool must be supported until it is defueled. The decontamination and decommissioning plan must be approved by the relevant authorities, and all appropriate licenses and permits must be obtained or modified. Consequently, the time between shutdown and the date of scrap availability is very unlikely to be less than 10 years. For the reference plants, metal masses in the activity-level categories are estimated for a time about 5 to 10 years after plant shutdown. For practical purposes, the largest decrease in radioactivity inventory is associated with the short-lived isotopes and occurs between shutdown and the earliest time that major demolition work can begin.

Subsequent decreases in the radioactive inventory over time are also significant. For example, a delay in operations on activated steel for about 100 years would result in a decrease by a factor of about 10^6 in the inventory of the five-year half-life Co-60 activation product. Such a delay could be an important means of reducing worker dose. Many utility planners have proposed postponing the start of major dismantling of activated power reactor facilities until 40 to 50 years after shutdown, and some are considering delay periods as long as 100 years.

The results of different decay times after shutdown (assuming a 1-Bq/g limit for the suspect radioactive category) are illustrated in Table 3.2 for light-water reactors (LWRs) in the U.S.A. Metals with fixed surface contamination are included in the "activated" category. In this case, the active stainless steel category does not change. Because the copper contains a small percentage of silver, the active copper mass does not change, either. After 50 years' delay, the masses of activated iron and mild steel, activated aluminum, and decontaminatable[3] metals of all categories with activity greater than 1 Bq/g are about 50% of the masses after 10 years. After 100 years' delay, the activated mass is about 40% of the 10-year mass, based on the advanced gas-cooled reactor (AGR) calculations. The decontaminatable mass after 100 years' delay is estimated to have dropped to 25% of that at 10 years. Table 3.2 lists the total iron and mild steel masses for U.S.A. power reactors assumed to be shut down in 2014 (the peak year) for three decay times: 50 years (the year 2024), 100 years (2074), and 150 years (2124) after start-up.

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[3] Corresponds to surface-contaminated — removable category.

TABLE 3.2 Example of Effects of Decay Period on Quantities of Scrap in Each Activity Category[a]

	Suspect Radioactive		Decontaminatable		Activated[b]	
Year	tons	%	tons	%	tons	%
2024	80,000	41	77,000	40	36,000	19
2074	136,000	71	38,000	20	18,000	9
2124	159,000	82	19,000	10	15,000	8

[a] Quantities of iron and mild steel projected for U.S.A. LWRs assumed to be shut down in the year 2014, for three different decay periods. The scrap is categorized as suspect radioactive if its activity level is likely to be 1 Bq/g or less.

[b] Includes metals with fixed surface contamination.

3.3.3 Categorization of Metals

For present purposes, it is necessary to employ broad classifications of scrap alloys, rather than to provide detailed data for the many alloys used in the industry. The metal classifications used are aluminum, copper, iron and steel, stainless steel, lead, nickel, and zirconium. The iron and steel category excludes metals that contain nickel. In general, iron or steel scrap containing nickel is classed as stainless steel (even if the nickel content is well below that of standard stainless steel alloys) because it is generally more feasible to upgrade the scrap by adding nickel (and other alloying elements) than it is to produce carbon/mild steel by removing the nickel. An example of this "stainless steel" classification applies to the typical U.S.A. water-reactor pressure vessel, which consists of thick-walled carbon steel clad with a stainless steel overlay for corrosion resistance. Although the reactor pressure vessel can be cut into sections for handling, it is not deemed feasible to separate the stainless steel from the base carbon steel. Other nickel alloys, such as Inconel, also are classed as stainless steel. Special nickel scrap, such as nickel diffusion barriers used in gaseous diffusion enrichment plants, also is classified as stainless steel.

3.3.4 Miscellaneous Assumptions

Some components of a nuclear power station have significant value as spare parts or as inputs to refurbishment of another plant. An active market already exists for nuclear-grade spare parts. As existing reactors are decommissioned, some used parts with acceptable life remaining may be much more valuable if salvaged as components for reuse in other nuclear plants than if recycled as scrap metal. It is uncertain how much of any particular power plant will become available for unrestricted release and how much will be reused in the nuclear industry. For these estimates, all decommissioned metal was assumed to be recycled as scrap.

Nuclear components and systems that are decommissioned contain materials other than metals — for example, insulation in electrical equipment, protective coatings on surfaces, and thermal insulation. In some cases these materials can be readily removed, but in other cases they cannot be removed and will remain adhered to the scrap. Such materials are not included here in any mass or volume estimates. Suspect radioactive reinforcing bar (rebar) in concrete is not included in the scrap estimates because the rebar is difficult and expensive to recycle from concrete structures and it constitutes a relatively small percentage of the total structure volume.

The estimates provided are based on typical plant operations, including duty-cycle events of reasonably high probability. The estimates do not reflect unusual increases in contaminated material types and masses that would be associated with accidents such as at Three Mile Island or Chernobyl.

3.4 SOURCES OF RADIOACTIVE SCRAP METAL

3.4.1 World Nuclear Power Plants

For this report, quantities of potential scrap metal have been estimated for the world listing of nuclear power plants (American Nuclear Society 1992; Nuclear Engineering International 1991, 1993). These estimates have been calculated with spreadsheet techniques and application of algorithms to estimate quantities of metal from each source on the basis of plant size and reactor type. Only plants listed as under construction or completed are included. Reactors of less than 100 MWe are excluded. Appendix A documents the methods used to obtain the inventory parameters applied in various countries, presents the input data employed in the application of the methodology, and concludes with summary output tables and illustrations.

Most of the metal scrap resulting from dismantlement of nuclear power plants is not radioactive. The nonradioactive scrap includes metal that normally has not been exposed to radioactivity during reactor operations (e.g., in a PWR turbine hall). However, just by being on a nuclear power station site, all metal may be exposed to activity from a blowdown, from off-gassing, or even from neutrons passing through the biological shielding. Therefore, all metal on the site will be required to be treated as suspect and surveyed before being moved off the site. Examples of nonradioactive scrap are plant cranes (except the reactor containment building crane), structural steel, secondary containment steel, emergency diesel generators, control-room hardware, and most of the facility wiring. Large quantities of other reactor-plant metal also can be nonradioactive. Lead is used primarily for instrumentation shielding and protection of maintenance workers. It will, in general, not be used in locations where activation is likely, and any surface contamination will be readily removable.

The country with the largest installed nuclear generating capacity is the U.S.A. The list includes 118 U.S.A. power plants (including 8 no longer in operation): 80 PWRs (Babcock & Wilcox, Combustion Engineering, and Westinghouse) and 38 BWRs (General Electric). Worldwide, PWR and BWR plants predominate, with significant numbers of pressurized

heavy-water reactors (PWHRs) (primarily of the Canadian deuterium-uranium [CANDU] type), gas-cooled reactors (GCRs), and advanced gas-cooled reactors (AGRs). The former Soviet Union versions of PWRs are designated as VVER, and the former Soviet Union also has a version of the light-water-cooled, graphite-moderated reactor, designated as RBMK (Chernobyl-type). Table 3.3 summarizes RSM data for the reference plants, which are described in Section A.2 of Appendix A.

In Appendix B, Tables B.1 through B.7 present the estimated amounts of nuclear power plant scrap metal potentially available annually by geographic region. Part A of each table presents the base case in which scrap metal from each plant is assumed to become available 50 years after start-up. This timing reflects a 40-year plant lifetime plus 10 years for achieving cold shutdown, draining and securing systems, and regulatory permitting. To illustrate the effects of radioactive decay, estimates of metal quantity were calculated for two additional time scenarios: 100 years after start-up (Part B of the tables), and 150 years after start-up (Part C of the tables). A noticeable shift from the high-activity categories (activated, surface-contaminated — fixed, and surface-contaminated — removable) toward the lowest activity category (suspect radioactive) occurs with each 50-year increase in delay. Clearly, an approach of SAFSTOR (Section 3.3.1) significantly reduces the potential worker exposures and required disposal resources, space, and costs. This approach is outlined in Broad (1986) for PHWRs and is clearly being considered for the AGRs because of the long-term decay activities presented in Regan et al. (1984).

Because nuclear power plants are likely to be dismantled over a number of years, the tables and figures in Appendix B present the inventory estimates as a flow of metal over time. To provide perspective on the total metal inventory, Table 3.4 provides estimates of total metal masses for major regions of the world and also worldwide totals. These estimates indicate the mass of each metal type that would be available in each contamination category from all reactors if each reactor was dismantled 50 years after its start-up date. The values shown as totals for regions and the world represent the available stock of metal, independent of time and contamination considerations. Thus, about 8.7×10^6 t of iron and steel scrap will be available from nuclear power plants worldwide, with major portions of that total originating in North America and Europe. Copper scrap mass is less than a third of that for iron and steel, and the quantities of the other metal types are much smaller.

3.4.2 Nuclear Fuel Cycle Facilities

The nuclear fuel cycle includes processing of the fuel outside the reactor. Such activities involve mining and milling, enrichment, fabrication, reprocessing, and refabrication facilities. No activation of metal components occurs in the fuel cycle facilities. RSM from the mining and milling segment will be contaminated by naturally occurring radioactive material. In general, most of the fuel cycle RSM will have surfaces that can be readily decontaminated. Two possible exceptions are fuel reprocessing components in which the chemicals have penetrated significantly into the surfaces and uranium enrichment components that have been contaminated by enrichment feedstock containing irradiated uranium. Fuel

TABLE 3.3 Reference Plant Metals Data

Parameter	Reference Reactors[a]									
	AGR	BWR	Magnox I	Magnox II	Magnox III	PHWR	PWR	RBMK	VVER 440	VVER 1000
Reactor Size (MWe, net)	NA[b]	1,000	<201	>201	NA	881	1,000	NA	440	1,000
Quantity of Metal (t)										
Aluminum										
Suspect radioactive	80	80	0	0	80	80	80	80	46	80
Surface-contaminated — removable	15	15	0	0	15	15	15	15	9	15
Surface-contaminated — fixed	0	0	0	0	0	0	0	0	0	0
Activated	5	5	0	0	5	5	5	5	3	5
Copper										
Suspect radioactive	3,900	4,900	1,900	2,400	3,900	4,900	4,900	4,900	2,840	4,900
Surface-contaminated — removable	80	80	50	50	80	80	80	80	46	80
Surface-contaminated — fixed	0	0	0	0	0	0	0	0	0	0
Activated	20	20	50	50	20	20	20	20	12	20
Lead										
Suspect radioactive	20	20	0	0	20	20	20	0	20	20
Surface-contaminated — removable	0	0	0	0	0	0	0	0	0	0
Surface-contaminated — fixed	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0

TABLE 3.3 (Cont.)

Parameter	Reference Reactors[a]									
	AGR	BWR	Magnox I	Magnox II	Magnox III	PHWR	PWR	RBMK	VVER 440	VVER 1000
Steel and Iron										
Suspect radioactive	12,770	5,000	3,800	4,690	12,770	8,000	8,290	19,248	12,030	19,248
Surface-contaminated — removable	5,630	6,700	4,950	6,225	5,630	6,000	6,700	7,156	4,669	7,156
Surface-contaminated — fixed	0	0	0	0	0	0	0	69	46	69
Activated	2,100	3,500	1,000	1,000	2,100	2,940	2,940	581	363	581
Stainless Steel										
Suspect radioactive	60	0	100	100	60	290	0	0	0	0
Surface-contaminated — removable	900	600	0	0	900	2,000	900	2,600	1,599	2,600
Surface-contaminated — fixed	0	0	0	0	0	200	300	0	0	0
Activated	165	670	0	0	165	2,100	670	406	254	406
Zirconium										
Suspect radioactive	0	0	0	0	0	0	0	0	0	0
Surface-contaminated — removable	0	0	0	0	0	0	0	0	0	0
Surface-contaminated — fixed	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	25	0	100	0	0

[a] See Section A.2, Appendix A, for discussion of reference plant types.

[b] NA = not applicable.

TABLE 3.4 Total Estimated Power Plant Scrap Metal Mass by Activity Category, 50 Years after Plant Start-Up, by Metal Type and by Region

Region/Activity	Mass (1,000 t) by Metal Type					
	Aluminum	Copper	Lead	Iron and Steel	Stainless Steel	Zirconium
North America						
Suspect radioactive	11	669	3	1,025	6	0
Surface-contaminated — removable	2	11	0	902	136	0
Surface-contaminated — fixed	0	0	0	–[a]	28	0
Activated	1	3	0	419	119	1
Total[b]	14	683	3	2,347	288	1
Europe						
Suspect radioactive	12	771	4	1,693	4	0
Surface-contaminated — removable	2	13	0	1,128	183	0
Surface-contaminated — fixed	0	0	0	2	25	0
Activated	1	4	0	406	92	–
Total[b]	15	788	4	3,229	304	–
Former Soviet Union						
Suspect radioactive	5	324	1	1,285	0	0
Surface-contaminated — removable	1	5	0	480	173	0
Surface-contaminated — fixed	0	0	0	5	0	0
Activated	–	1	0	39	27	2
Total[b]	7	331	1	1,809	200	2
Asia						
Suspect radioactive	5	335	2	478	2	0
Surface-contaminated — removable	1	5	0	456	61	0
Surface-contaminated — fixed	0	0	0	0	12	0
Activated	–	1	0	216	55	–
Total[b]	6	341	2	1,150	130	–
Rest of World						
Suspect radioactive	1	40	–	82	1	0
Surface-contaminated — removable	–	1	0	55	12	0
Surface-contaminated — fixed	0	0	0	–	2	0
Activated	–	–	0	22	8	–
Total[b]	1	41	–	159	23	–
World Total[b]						
Suspect radioactive	34	2,139	10	4,563	13	0
Surface-contaminated — removable	6	35	0	3,021	565	0
Surface-contaminated — fixed	0	0	0	7	67	0
Activated	2	9	0	1,102	301	3
Total[b]	43	2,183	10	8,693	946	3

[a] – denotes less than 1,000 t.

[b] Totals may not add because of rounding.

reprocessing metal mass includes scrap from the decommissioning of the West Valley, New York, reprocessing facility as well as from reprocessing facilities outside the U.S.A.

The facilities used in the enrichment segment of the fuel cycle are large. In fact, the largest building in the U.S.A. is the K-25 facility at Oak Ridge, Tennessee, which has about 120 acres of floor space (DeLozer 1992). The U.S.A. uses gaseous diffusion enrichment; both gaseous diffusion and centrifuge plants are used in other countries.

Table 3.5 lists world enrichment facilities, including their capacities in thousands of separative work units per year (kSWU/yr) (Nuclear Engineering International 1992). The U.S.A. has three gaseous diffusion facilities: Paducah (11,300 kSWU/yr), Portsmouth (7,900 kSWU/yr), and Oak Ridge (7,700 kSWU/yr). DeLozer (1992) reports that the K-25 site at Oak Ridge contains 9,000 t of nickel and that decommissioning of this plant will generate over 180,000 t of scrap steel. The metal quantities from this site alone are roughly equivalent to the cumulative total of the 75 t of nickel and 1,500 t of scrap steel per U.S.A. power plant. The three U.S. enrichment facilities combined had scrap piles estimated at over 92,000 t of carbon steel and 6,000 t of aluminum in 1994 (DOE 1995).

Hertzler et al. (1993) provide information for a number of facilities, including the three U.S.A. gaseous diffusion enrichment plants. Although the authors use some alloy categories that do not correspond to those in this report, their values for the enrichment facilities are summarized in Table 3.6. These facilities are somewhat unique in having a relatively large mass of nickel.

Baxter and Bradbury (1992) describe the nearly completed decommissioning of the 650-kSWU/yr Capenhurst diffusion plant. The Capenhurst data provide a good indication of the large potential for decontamination of this type of scrap, because waste site capacity limitations provided strong incentive for recycling rather than burial. In fact, Baxter and Bradbury (1992) report that more than 99% of the total structure and contents of Capenhurst will be recycled as clean material. The Capenhurst data, for 650 kSWU/yr, are given in Table 3.7. By completion of the Capenhurst dismantling, approximately 40,000 t of carbon steel, 11,000 t of aluminum, and 3,500 t of electrical motors were cleared for release (Clements 1994).

3.4.3 Military Facilities

Military sources of RSM include naval propulsion reactors, production reactors, nuclear weapons production facilities, and related fuel cycles facilities (Table 3.8). Worldwide, about 600 propulsion reactors were on commissioned naval vessels in 1990 (Nucleonics Week 1993c). This figure exceeds the worldwide total of nuclear power plants. Enrichment facilities originally constructed and operated for military purposes have been extensively refurbished and redirected to civilian nuclear power programs. For consistent presentation, all enrichment facilities have been combined under civilian fuel cycle enrichment facilities.

TABLE 3.5 World Enrichment Plants

Country	Plant	Capacity (kSWU/yr)	Process	Status
Argentina	Pilcaniyeu-1	20	Diffusion	Operable
	Pilcaniyeu-2	100	Diffusion	Construction
Brazil	Resende	10	Jet nozzle	Construction
China	Lanchow	200	Diffusion	Operable
France	Tricastin	10,800	Diffusion	Operable
Germany	Gronau	400	Centrifuge	Operable
	KfK	50	Jet nozzle	Operable
Japan	Hyuga	2	Chemical	Operable
	Ningyo-Toge (pilot)	200	Centrifuge	Operable
	Ningyo-Toge (demo)	50	Centrifuge	Operable
	Rokkasho-Mura 1	150	Centrifuge	Construction
	Rokkasho-Mura 2	1,350	Centrifuge	Planned
Netherlands	Almelo	1,200	Centrifuge	Operable
Pakistan	Kahuta	5	Centrifuge	Operable
South Africa	Valindaba	300	Helicon	Operable
United Kingdom	Capenhurst Urenco	850	Centrifuge	Operable
	Capenhurst BNFL	650	Diffusion	Shut down
U.S.A.	Paducah	11,300	Diffusion	Operable
	Portsmouth	7,900	Diffusion	Operable
	Oak Ridge	7,700	Diffusion	Shut down
Former Soviet Union	Siberia	10,000	Diffusion	Operable

Current plans for disposition of U.S.A. nuclear-powered submarines call for disposal of radioactive metal (about 1,000 t per reactor) as low-level radioactive waste (LLW). By the end of 1990, 37 U.S.A. nuclear submarines had been retired from active service, and 14 of the reactor compartments had been disposed of as LLW at a government burial site, leaving 23 more reactor compartments in storage awaiting disposition. About 100 additional U.S.A. nuclear-powered submarines are expected to be decommissioned over the next 20-30 years (ORNL 1991). Present policy in the U.S.A. is for the fuel to be removed at Bremerton, followed by removal of surface contamination deposits by acid etching. After installation of additional bulkhead facings or canning plates, the isolated reactor compartment is barged to the Hanford area for land burial. Former Soviet Union practice has been to dispose of

submarines at sea or by beaching. The estimated numbers of naval propulsion reactors as of 1990, broken down by country, are as follows: 400 Russian, "upwards of 160" U.S.A., 21 United Kingdom, 10 French, and 6 Chinese (Nucleonics Week 1993c). If the value of 1,000 t of metal per reactor is appropriate for the worldwide inventory, there would be a potential for about 600,000 t of activated stainless steel scrap from decommissioning of naval propulsion reactors. Accelerated decommissioning of naval reactors could have significant impact on burial facilities for a limited number of years.

TABLE 3.6 U.S.A. Uranium Enrichment Plant Metal Scrap

Metal Type	Metal Mass (t)
Aluminum[a]	27,000
Copper	7,000
Steel/iron	192,000
Stainless steel[b]	12,000
Nickel	58,000

[a] Includes Al/Cu alloy.

[b] Includes nickel-plated steel.

Source: Hertzler et al. (1993).

All of the U.S.A. weapons production reactors fall into two types: heavy-water reactors (HWRs), all at Savannah River; and light-water-cooled, graphite-moderated reactors (LGRs), all at Hanford. United Kingdom production reactors are of the GCR type. The former Soviet Union built a different type of LGR production reactor, the ancestor of Chernobyl-type RBMK reactors. Table 3.9 lists the U.S.A. production reactors: five HWRs, and eight LGRs (DOE 1980). One additional Hanford LGR, the N Reactor, was equipped with power generation equipment and is listed as a shut down power reactor in the American Nuclear Society's 1992 World List of Nuclear Power Plants. Because of the unique reactor designs and the absence of power generation equipment, scrap metal from production reactors is not included in the inventory, except reactors equipped to generate at least 100 MWe. For inventory completeness, the N Reactor is assigned the scrap values of the reference RBMK plant, although the detailed designs are, in fact, quite different.

TABLE 3.7 Capenhurst Enrichment Plant Scrap

	Metal Masses (t)			
Material	Steel	Aluminum	Other	Total
Suspect radioactive	NA[a]	NA	NA	114,000
Surface-contaminated — removable	9,200	3,000	1,300	13,500
Activated and surface-contaminated — fixed	NA	NA	NA	1,000

[a] Data detail not available.

TABLE 3.8 Military Facilities That Are Sources of Radioactive Scrap Metal

Naval propulsion reactors, primarily submarine
Production reactors[a]
Military enrichment facilities[b]
Nuclear weapons production
Military fuel fabrication — propulsion reactors
Military fuel fabrication — production reactors
Reprocessing facilities for military programs

[a] See Table 3.9.

[b] Included in list of enrichment plants in Section 3.4.2 (Table 3.5).

TABLE 3.9 List of U.S.A. Production Reactors

Reactor	Type[a]	Start-Up	Year Shut Down
Savannah River Site			
C Reactor	HWR	1955	[b]
K Reactor	HWR	1954	[b]
L Reactor	HWR	1954	1968
P Reactor	HWR	1954	[b]
R Reactor	HWR	1953	1964
Hanford Site			
B Reactor	LGR	1944	1968
C Reactor	LGR	1952	1969
D Reactor	LGR	1944	1967
DR Reactor	LGR	1950	1964
F Reactor	LGR	1945	1965
H Reactor	LGR	1949	1965
KE Reactor	LGR	1955	1971
KW Reactor	LGR	1955	1970

[a] HWR = heavy-water reactor; LGR = light-water-cooled, graphite-moderated reactor.

[b] Future status uncertain; not currently operating.

3.4.4 Other Facilities

The category of "other facilities" covers a wide span of items, including small research and development and training reactors, large research reactors, developmental power reactors, small university accelerators, world-class high-energy accelerators, industrial sterilizer plants, industrial radiography equipment, and various medical facilities. Consistent identification of all such facilities across all categories and across different national jurisdictions is beyond the scope of this study.

A 1980 report by the U.S. Department of Energy (DOE 1980) lists 162 test, research, and university reactors (including medical), and 12 additional reactors of this type from military programs in the U.S.A. Although this total of 174 reactors exceeds the number of U.S.A. power reactors, the scrap metal mass potentially available from this reactor category is not a significant fraction of that from power plants.

RSM from accelerators is primarily activated, rather than surface-contaminated. Levels of contamination can vary greatly with design, accelerator beam currents, and accelerator energy. Numerous alloys are used in accelerators, including high-purity magnet iron, multicomponent superconducting magnet coils, exotic vacuum-chamber alloys, and others. Decommissioned research accelerators traditionally have served as a source of recycled material for newer research facilities, thus making it difficult to estimate overall types and quantities of radioactive scrap from accelerators. For example, the magnets from the 10-GeV Zero Gradient Synchrotron (ZGS) accelerator at Argonne National Laboratory in the U.S.A. were transferred to the Fermilab Tevatron for use as shielding. Much of the ZGS civil engineering structure was used for the Argonne National Laboratory Intense Pulsed Neutron Source facility (Martin 1993). Although older accelerators have been important sources of material for new accelerator facilities and projects, they do not represent a large total quantity of RSM compared with the overall quantities available from other kinds of facilities.

Research and development reactors are divided into two groups for this study: (1) test, research, and university reactors used as sources of radiation for basic and applied research, and (2) reactor development reactors. There are many different test, research, and university reactor designs and a wide array of power levels, ranging from many "zero power" facilities up to a few high-powered test reactors of 100 MWe or more.

Typical research power levels are orders of magnitude less than those of power reactors, and most operate at atmospheric pressure. Thus, levels of activation and contamination per unit volume of scrap typically are much lower for these reactors than for power reactors, and the quantities of metal per reactor typically are much lower than those from power reactors. Excluding reactors that have been dismantled (such as the Argonne National Laboratory CP-3), transient reactors that have very little structure and that operate at negligible average power (such as the Sandia Pulsed Reactor II), and very-low-power reactors (such as the Georgia Tech Research Reactor), 105 research and development facilities exist in the U.S.A. (DOE 1980). These reactors have a wide range of design characteristics, power levels, relative levels of radioactivity, and metal quantities. Four of these 105 reactors

have power level ratings of 100 MWe or more, and they more properly belong with the developmental reactors, leaving 101 reactors in this general category.

The oldest existing research reactor is the Argonne National Laboratory CP-5 facility, which is now being decontaminated and decommissioned for unrestricted site use. Recyclable radioactive activated/contaminated metal scrap from CP-5 is to be provided to the Scientific Ecology Group Inc. (SEG) Smelter Facility in Oak Ridge, Tennessee, as authorized by the U.S. Department of Energy. The types of materials and the quantities of each that are recyclable are as follows (Ditch 1992):

>90% stainless steel	About 20 t
>90% carbon steel	About 20 t
55% copper, 44% carbon steel	About 1 t each (electric motors)

Argonne National Laboratory performs presorting by commodity before shipment, and Scientific Ecology Group does additional sorting, as feasible, upon receipt. Motors are to be disassembled at the smelter facility, and it is expected that nonmetallic materials (e.g., insulation) will be burned off during smelting. The intent is to obtain products that are sufficiently pure to be stockpiled by the U.S. Department of Energy for use within its programs. Aluminum recycling is not included in the CP-5 program scope because at this time there is not sufficient demand for the aluminum. Although aluminum is present in CP-5, it is not present in large amounts in many research reactors. Multiplying the CP-5 data by 101 yields a rough order of magnitude estimate of the amount of RSM potentially available from research reactors in the U.S.A. The resulting estimates (2,000 t of stainless steel, 2,100 t of carbon steel, and 100 t of copper) are very small compared with the magnitudes of scrap metal available from the U.S.A. power reactors.

Reactor development reactors tend to share the characteristics of the full-sized machines of the same types. Many, of course, represent end points in development and have few or no full-sized counterparts. The American Nuclear Society's 1992 World List of Nuclear Power Plants lists 16 U.S.A. developmental plants as no longer in service. One of these (the Shippingport PWR) has been dismantled, leaving a site capable of unrestricted use. The remaining 15 are categorized as follows: 6 BWR; 4 PWR; 2 high-temperature, gas-cooled reactors (HTGRs); 1 liquid-metal, fast breeder reactor (LMFBR); 1 LGR; and 1 liquid-metal, graphite-moderated reactor (LMGMR). Adding the four test reactors excluded from the research list yields a total of only 19 U.S.A. development reactors, small in number and small in power compared with the large U.S.A. power reactor inventory. Developmental reactors are excluded from the scrap metal estimates if they have electrical output ratings of less than 100 MWe. Although the liquid-metal reactor (LMR) has been developed for demonstration and precommercial operation in several countries, relatively few have electrical output of at least 100 MWe. All of the larger LMRs are one-of-a-kind plants with highly uncertain operating lifetimes controlled more by external financial exigencies and governmental policy than by technical matters. For these reasons, particularly the unknown end-of-life, LMRs are excluded from the scrap metal estimates.

3.4.5 Operations and Maintenance

Long before the end of a reactor's life, metal scrap will be generated during operating and maintenance activities involving major repairs. Scrap of this type will range from valves to steam generators, and may even include such items as reactor vessel heads (Nucleonics Week 1993b). The quantities of such materials depend upon such factors as reactor class, vendor, architect/engineer, age, and the operator.

In addition to the reactors themselves, operation and maintenance and repair streams must also be considered. Components in these streams range from small items up to steam generators. Reliability histories could be used to estimate such items as valve replacements, new instruments, and other components, and these estimates could then be factored into predicted schedules. However, most of these items are trivial in size compared with the total metals inventory. Steam generator replacements, however, can be significant. On the basis of the replacement mass for a North Anna-1 steam generator (Nucleonics Week 1993a), a nominal steam generator replacement would generate about 800 t of contaminated steel of various alloys. Currently, U.S.A. practice is to treat the removed steam generators as radioactive waste. These replacement operations appear to be a significant source of RSM. Because of uncertainties in schedule and in identification of reactors requiring steam generator replacement, these replaced generators are not included in the scrap metal estimates.

3.4.6 Extraction Equipment

Beyond the nuclear industry, significant quantities of RSM are also associated with other areas of endeavor. The source of this RSM is equipment contaminated by naturally occurring radioactive materials. Typically, the radioactive material is brought to the surface with the required product and is left on the equipment as a scale, in the equipment as a sludge, or in the spoil from purification processes. The main sectors with such problems are the petroleum industry and phosphate mining.

Dehmel et al. (1992) state that there were more than 852,000 oil and gas wells in the U.S.A. in 1991 and that for a typical 10-well production facility there was about 35,000 ft^3 total disposal volume of components and 2,300 ft^3 of sludge and scale contaminated with naturally occurring radioactive material. Not all wells are contaminated, ranging from a "few" in some states up to 90% in other states. The main radiological contributors in oil pipe scale and sludge are Ra-226 and -228, with some uranium and thorium. In gas wells, radioactivity is associated with the radon daughters Pb-210 and Rn-210. Specific scale activity ranges from 3.7 to 15,000 Bq/g. The measured exposures range from 0.05 to 4 mR/h (5×10^{-7} to 4×10^{-5} Gy/h) for outside equipment up to 15 mR/h (1.5×10^{-4} Gy/h) inside. Although the doses are low and the scale and sludge can be removed, the large number of wells worldwide implies that the mass of scrap involved may be substantial. Dehmel et al. (1992) estimate that about 3×10^6 t of metal scrap is produced annually.

3.5 ESTIMATES OF TOTAL SCRAP METAL INVENTORY

Estimation of potential quantities of RSM potentially available worldwide is hindered both by a lack of published data and by the uncertainties associated with weapons facilities. It is likely that three categories of facilities — nuclear power, fuel cycle, and weapons production — are the largest potential sources of contaminated scrap metal, although the quantity of naturally contaminated petroleum extraction equipment and piping may also be substantial. Table 3.10 summarizes the inventory categories for which published estimates of scrap metal masses are available. The estimate for petroleum extraction equipment, however, is an annual flow of scrap, while the rest of the figures are for the total stock of contaminated, or suspect, metals.

More than 9×10^6 t of carbon steel will be available from nuclear power plant and uranium enrichment plant dismantlement, with major portions of that amount originating in North America and Europe. The mass of copper scrap is about 2×10^6 t, and that of stainless steel about 1×10^6 t. The quantities of other metal types are much smaller. The distribution of metal masses among the contamination categories varies by metal type, but the amount of potential scrap metal that is activated or has fixed contamination ranges from a very small portion for aluminum and copper to almost half of the total quantity for stainless steel (see Appendix B). The inclusion of scrap from weapons facilities (along with

TABLE 3.10 Summary of Radioactive Scrap Metal Inventory Estimates from Various Sources by Metal Type

	Mass (1,000 t) by Metal Type					
Source	Aluminum	Copper	Lead	Iron and Steel	Stainless Steel	Nickel
U.S.A.						
Power plants	14	683	3	2,347	288	NA[a]
Military	NA	NA	NA	NA	160	NA
R & D reactors	NA	–[b]	NA	2	2	NA
Extraction equipment	NA	NA	NA	3,000[c]	NA	
Enrichment plants	27	7	NA	192	12	58
World (includes U.S.A.)						
Power plants	43	2,183	10	8,693	946	NA
Military	NA	NA	NA	NA	600	NA

[a] NA = No data available.

[b] Less than 1,000 t.

[c] Unspecified metal (includes piping, tanks, and equipment), annually available quantity according to Dehmel et al. (1992).

that from other sources) would probably more than double these estimates, so the total inventory of potential metal scrap is on the order of 3×10^7 t. On an annual basis, this inventory could produce recycling flows of 5×10^5 t/yr of iron and steel, 1×10^5 t/yr of copper, and 4×10^4 t/yr of stainless steel over a 50 year period.

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4 INTERNATIONAL SCRAP METAL MARKET

Scrap metal recycling provides a significant portion of supply for all types of metal. For instance, according to the Institute for Scrap Recycling Industries (1990), scrap processors in the U.S.A. annually handle approximately:

- 54.5×10^6 t of scrap iron and steel,
- 6×10^6 t of scrap stainless steel,
- 2.7×10^6 t of scrap aluminum,
- 1.6×10^6 t of scrap copper,
- 0.9×10^6 t of scrap lead, and
- 0.2×10^6 t of scrap zinc.

This section characterizes the international metal recycling industry for iron and steel scrap, stainless steel, aluminum, copper, lead, nickel, and zinc and assesses the market impact that a radioactive scrap metal (RSM) recycling program might have.

Section 4.1 describes the "product" (scrap metal) and introduces commonly used terminology and processes employed by the metal recycling industry. Although most of the information presented pertains to U.S.A. domestic markets and processes, it should also be relevant for any industrialized country (the primary sources and users of scrap metals). Information regarding markets and technology used in other countries is presented where available. Section 4.2 describes the forces that shape the international market and influence market viability. International scrap metal trade data are presented to identify those countries that are major exporters or importers of scrap metal. Section 4.3 discusses current industry practices for handling contaminated scrap, including procedures for dealing with contaminants ranging from chemicals and processing oils commonly found in scrap to radioactivity and hazardous chemicals. Section 4.4 summarizes the potential for market impacts from recycling nuclear industry scrap.

4.1 SCRAP METAL TERMINOLOGY AND PROCESSES

4.1.1 Scrap Metal Terminology

Metals are usually divided into two categories: ferrous (which includes all iron-based metals such as cast iron and steel) and nonferrous (which includes all other metals). For this report, "nonferrous scrap" refers only to aluminum, copper, lead, nickel, stainless steel, and zinc.

Nonferrous metal refiners are classified as either primary or secondary. Primary smelters refine metal from ores, and secondary producers refine metal from scrap. These definitions are somewhat flexible, however, since some primary nonferrous smelters use scrap as input. By contrast, the steelmaking industry makes no distinction between primary and secondary production because scrap iron is generally recycled at the same plants that produce iron from ore. In recent years, however, minimills have evolved around electric arc furnaces using 100% scrap as inputs, and these plants can be viewed as "secondary" ferrous metal plants.

All scrap metal can be broadly classified into three generic types: "home," "industrial," and "obsolete," depending on its source or origin. Home scrap is produced in mills and foundries as a direct result of metal refining, casting, and milling operations and usually does not leave the plant where it originates. Home scrap is sometimes referred to as "runaround" or "revert" scrap. Industrial scrap (sometimes called "prompt" or "new" scrap) is produced by industrial sources during metal machining processes. Obsolete scrap comes from broken, worn-out, discarded objects, or objects that have otherwise outlived their usefulness.

Ferrous scrap is broadly classified into home and purchased scrap, depending on whether the scrap was generated at the mill or obtained from scrap dealers, respectively (Figure 4.1). Home scrap now accounts for about one fourth of total ferrous scrap consumption. In recent years, this fraction has fallen significantly because of improved technologies, such as continuous casting, and more efficient milling operations. Purchased scrap includes both industrial and obsolete scrap. Industrial scrap averages about one-third of total ferrous scrap consumption. The auto industry is the largest single source of industrial scrap. Obsolete scrap, almost half of the total, constitutes the remaining ferrous scrap consumption.

Although the volume of nonferrous scrap is not as large as that of ferrous scrap, it is more valuable. In 1991, the value of recycled nonferrous metals exceeded $\$7.5 \times 10^9$ in the U.S.A. (Jolly et al. 1993, p. 1), compared with $\$5.38 \times 10^9$ for ferrous scrap.

Nonferrous scrap is classified as either old scrap or new scrap (Figure 4.2), depending on whether the scrap is in the form of an end product. New scrap includes residues from metal fabrication and machining and from refining processes. New scrap is further classified as either runaround (home) or new purchased (industrial) scrap. As with ferrous scrap, runaround scrap is new scrap that has never left the plant that produced it. Purchased scrap is new scrap that is purchased by secondary refiners, much like ferrous industrial scrap. Old scrap, all of which is purchased, is discarded, used, worn out, or technologically obsolete objects.

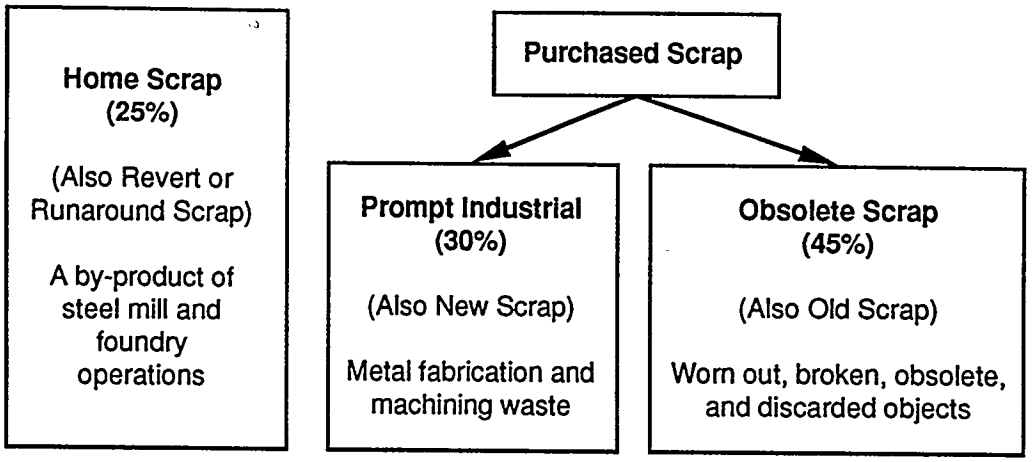


FIGURE 4.1 Ferrous Scrap Categories

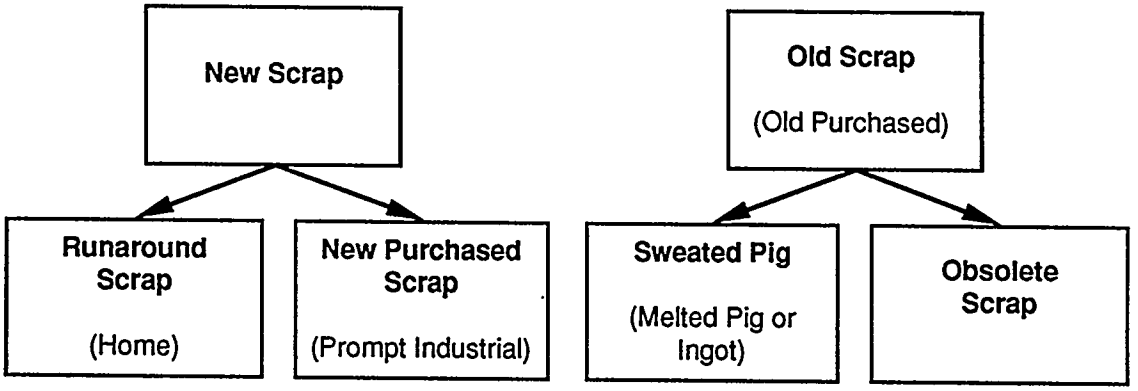


FIGURE 4.2 Nonferrous Scrap Categories

4.1.2 Scrap Collection and Processing

This section discusses purchased (industrial and obsolete) scrap collection and processing. Home scrap will not be discussed since it rarely leaves the foundry and is not handled by scrap processors.

4.1.2.1 Industry Participants

In the 1991-1992 reporting period, the U.S.A. secondary nonferrous metals industry (Standard Industrial Classification [SIC] 3341) had 88 companies reporting sales of $\$4.129 \times 10^9$ and 15,300 employees. The scrap and waste materials industry (SIC 5093) included 281 companies with $\$9.780 \times 10^9$ in sales and 25,700 employees (Towell 1992).

Figure 4.3 presents an overview of the scrap collection process. In this process, there are four functional roles for scrap market participants: collector, processor, broker/dealer, and consumer. These roles are described below.

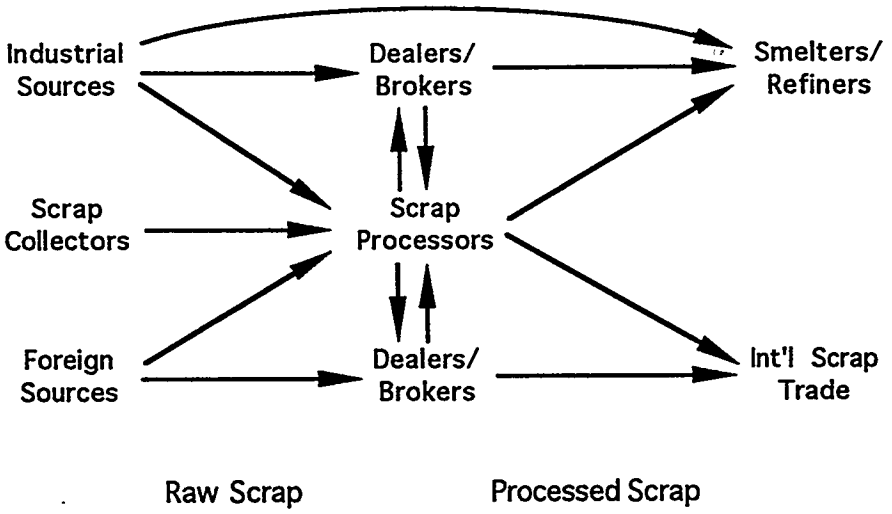


FIGURE 4.3 Scrap Collection Overview

Collectors

Collection is the first step in the scrap recycling process, and collectors gather scrap from its various sources and make it available for processing. Obsolete scrap comes from a variety of sources: government facilities, utility companies, auto dismantlers, railroads, shipyards, airlines, building dismantlers, junk collectors, and private citizens.

Processors

Scrap processors play a pivotal role by sorting, categorizing, and preparing scrap so it can be efficiently used by the scrap consumer. They employ a large variety of equipment (such as shears, balers, shredders, crushers, and cutting torches) and may incur significant capital costs for this equipment. The shredder has had an enormous impact on the scrap metal industry. An automobile shredder can reduce an automobile to fist-size pieces of scrap in less than one minute. The iron and steel fraction is magnetically separated from the other materials to produce high-quality scrap. Shredders, depending on their size, can process from 25,000 to 250,000 cars per year. Thus, shredders have made a large quantity of high-quality scrap metal available for recycling.

Brokers/Dealers

In the scrap metals industry, brokers buy and sell scrap but do not take physical possession of it. Dealers differ from brokers in that they do take possession of the scrap. Processors and buyers usually deal directly, but sometimes a scrap broker or dealer will serve as an intermediary. Brokers and dealers survive by having knowledge of the market superior to either the processor or the buyer. Because the scrap market is a collection of regional markets, local supply and demand imbalances can exist. Brokers gather information about

remote markets and serve to facilitate trade by purchasing scrap where it is in excess supply and selling it where it is in demand.

Brokers and dealers also facilitate international trade by assuming some of the risks that can be involved. The international market is riskier because the lead time on orders can be from 90 to 120 days, compared with 30 days domestically (Institute of Scrap Iron and Steel 1984). The long lead time exposes the broker to adverse movements in scrap prices, as well as in foreign exchange rates. Brokers and dealers may also facilitate trade by providing financing for deals.

Consumers

Scrap consumers include secondary refiners, mills, and foundries. Mills and foundries demand scrap because it is cheaper to remelt scrap than to produce metal from ores.

4.1.2.2 Scrap Grades

Raw scrap is "graded" in order to assess the quantity and type of "tramp" or residual elements present in the scrap. Hundreds of grades exist for ferrous and nonferrous scrap metals. Tramp elements are materials or items that are difficult to remove during the smelting and refining processes, usually because of their chemical and metallurgical similarity with the metal of interest. Tramp elements also have a negative impact on the suitability of the metal for its intended use. For example, copper is considered to be a tramp element in ferrous scrap because it makes the metal difficult to work cold; therefore, the price of ferrous scrap decreases with increased copper content. However, steel used for structural and bar shapes, for example, can tolerate a greater fraction of copper content.

Of the three types of scrap (home, industrial, and obsolete), obsolete scrap is the most difficult to grade because the least is known about it. Knowledge of the scrap's prior use can give important clues about the quality of the metal and about possible alloying elements or contaminants. For example, products made from rolled steel tend to be higher quality because the steel must have fewer residuals to be able to tolerate the cold-rolling process. In contrast, cast products can tolerate a higher level of tramp elements, so they are generally assumed to be of a lower-quality steel.

Raw industrial scrap is generally easier to grade than obsolete scrap because the seller can document the quality of the metal. Industrial lubricants and process residues may contaminate the scrap, but in most cases these contaminants are burned off when the scrap is refined.

4.1.3 Scrap Smelting and Refining Processes

The secondary smelting and refining phase of scrap metal recycling is not part of the scrap metal industry per se, but since the scrap industry is so closely linked to secondary refining, a brief discussion of the major processes is warranted.

4.1.3.1 Scrap Iron and Steel Recycling

Recycled ferrous scrap supplied 61% of U.S.A. raw iron and steel requirements in 1990, up from 51% in 1970 (Brown 1992). In 1991, domestic consumers used 40.7×10^6 t of ferrous scrap, with a value of $\$4.15 \times 10^9$ (Brown 1993, p. 1). In addition, 9.3×10^6 t of ferrous scrap with a value of $\$1.23 \times 10^9$ was exported.

Figure 4.4 illustrates the flow of iron from production through recycling. Most ferrous scrap is recycled in one of three ways — it may be charged to the blast furnace along with iron ore; it may be added directly to steelmaking furnaces; or it may be remelted at foundries. Because most ferrous scrap is recycled as steel, the steelmaking process is described in greater detail below.

In the past, steelmaking was highly integrated, which meant that one firm owned or controlled every step of the process, from mining the ore to milling the finished product. Integrated mills typically employed blast furnaces to produce molten refined iron, called pig iron, from the iron ore. Blast furnaces operate by blowing hot gas on raw ore, coke, limestone, and scrap. Chemical reactions cause the iron ore to be reduced to molten iron.[1] The more volatile impurities evaporate and are blown off in the flue gas, while the less volatile impurities are drawn off in the slag formed from the limestone. The molten pig iron is then transferred to the steelmaking furnaces, which may be one of three types: basic oxygen furnace (BOF), electric arc furnace (EAF), and open-hearth furnace. Alloying elements are added to the iron in the steelmaking furnace, and the chemical composition of the mixture is adjusted to produce steel. The molten steel is transferred to either a continuous-casting machine or to ingot molds (Brown 1992). Continuous cast steel production represented 67% of total U.S.A. domestic raw steel production in 1990. In either case, the steel solidifies and is then milled into the primary shapes: blooms, billets, and slabs. Virtually all steel products are manufactured from these primary mill shapes.

Electric arc furnaces recently have become an important source of steel as steelmaking technology has evolved. Mills with EAFs usually have a smaller steelmaking capacity than integrated steel plants, but they may have larger scrap throughput.

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[1] Recent technical innovations include the direct reduction process, which produces direct reduced iron (DRI) by chemically treating iron ore without melting it. At present this technology is not economically feasible in most parts of the world, and only a small fraction of iron is treated this way. DRI is expected play a more prominent role in the future.

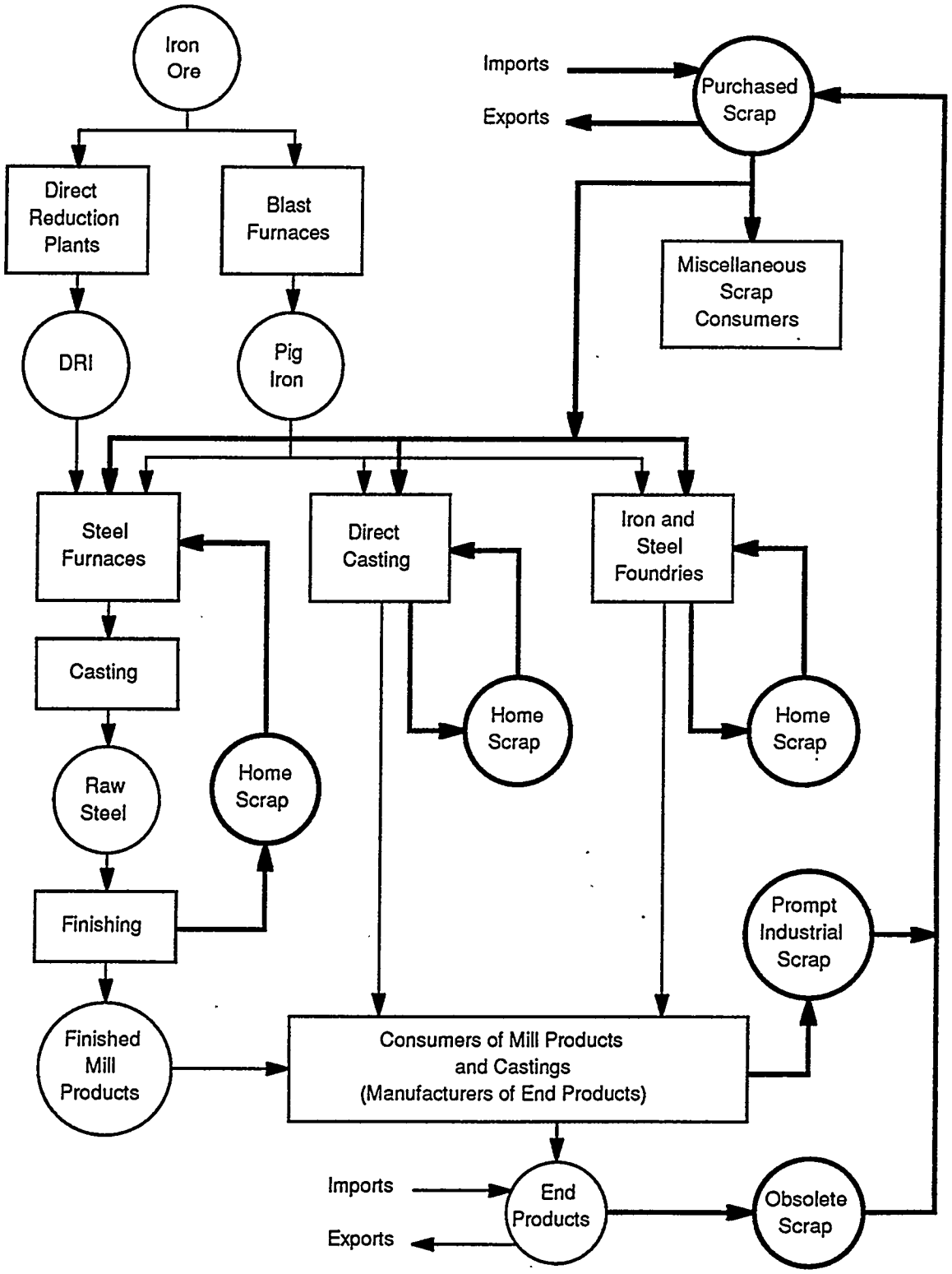


FIGURE 4.4 Iron Scrap Flow Diagram (Source: Based on U.S. Bureau of Mines 1985)

They do not require the blast furnace step of the steelmaking process. Electric arc furnaces use nearly 100% scrap iron and steel for the furnace charge. Basic oxygen furnace processes typically use approximately 30% scrap, but a significant portion of this scrap is runaround (home) scrap. Open-hearth furnaces use about 50% scrap, but this fraction can vary widely. As indicated in Table 4.1, although BOF plants generally have larger production capacities than EAF systems, scrap throughput is greater in the EAF systems. In 1990, the shares of U.S.A. domestic steel produced in EAF, BOF, and open-hearth furnaces were 37%, 59%, and 4%, respectively (Brown 1992). A study by the U.S. Bureau of Mines (Brown 1992) found that the steelmaking industry's reliance on purchased (new plus old) scrap had increased sharply over the past 20 years. Total ferrous scrap consumed by U.S.A. steel mills was composed of 16% new (prompt industrial) scrap and 24% old (obsolete) scrap in 1970, compared with 29% new scrap and 44% old scrap in 1990 (Brown 1992).

Mills with electric arc furnaces have an economic advantage over integrated steel mills employing the basic oxygen process because the former are more energy efficient, emit less pollution, and consume scrap, which is relatively plentiful in industrially developed countries. As the number and production capacity of electric arc furnaces increases, scrap iron and steel will increase in value as input to these mills.

4.1.3.2 Secondary Nonferrous Metal Refining

Nonferrous metals are usually refined at secondary refiners (though some scrap is sent to primary refiners) and are typically handled in smaller quantities than ferrous metals. This section discusses typical secondary nonferrous refining processes and notes process differences among metals (aluminum, copper, lead, nickel, zinc).

TABLE 4.1 Size Ranges of Basic Oxygen Process and Electric Arc Furnace Steel Mills[a]

		Electric Arc Furnaces	
Parameter	BOF	Large	Minimill
Mill capacity (10^6 t/yr)	0.9-2.4-4.5	0.4-0.8-2.7	0.05-0.39-2.7
Furnace size (t)	86-195-327	73-136-363	9-54-136
Scrap throughput (10^6 t/yr)	0.27-0.73-1.36	0.4-0.8-2.7	0.05-0.39-2.7

[a] Data presented are low, typical, and high values.

Source: Dehmel et al. (1992, Table B-1).

Aluminum

Aluminum recovery from scrap has increased tenfold since 1950 in the U.S.A., and recovery from old scrap has grown even more rapidly over the same time (Jolly et al. 1993). This increase in recycling in the U.S.A. is indicative of the international trend toward increased scrap recovery. In 1991, an estimated 2.5×10^6 t of metal was recovered from purchased scrap in the U.S.A., of which about 60% was old scrap. The quantity of old scrap recovered equalled almost 30% of the total domestic aluminum metal demand for 1991. The percentage is similar in other Western countries. One major factor in this trend has been increased recycling of used beverage containers. Figure 4.5 illustrates the flow of aluminum scrap through the recycling process.

Table 4.2 presents scrap consumption data by industry segment from 1989 to 1991. Primary (integrated) producers are the largest consumers of scrap aluminum, but much of it comes form their industrial customers. Thus, the scrap used by primary producers tends to be more segregated than that used by the secondary smelters. Independent secondary producers play a crucial role in the aluminum recycling process. Their sole function is to convert aluminum scrap into a marketable product, almost exclusively alloys for the die-casting industry.

Copper

World copper production in 1990 totaled 9.4×10^6 t (Jolly and Edelstein 1992). Copper scrap annually accounts for about 19% of world copper production. Figure 4.6 shows the flow of scrap copper through the recycling process. In recent years, about 40% of refined copper produced in Western Europe and about 22% of refined copper produced in the U.S.A. was derived from copper scrap. (Jolly et al. 1993).

Copper has an excellent potential for recovery because few of its uses are dissipative in nature. Only about 0.5% of total copper consumption may be unretrievable due to use in applications such as chemicals. Scrap recovery is very price and cost sensitive; more obsolete scrap appears as the price of primary copper increases. Secondary copper costs only about half as much to produce as primary copper. Production of copper from scrap requires less than half the energy required for production from ore (Jolly et al. 1993).

Copper scrap also follows the scrap designations of old and new scrap. While new scrap can generally be remelted, most old scrap must be reprocessed either by smelting and refining or by more complex processes, such as leaching and electrowinning, to form a pure copper product (Jolly et al. 1993). In the U.S.A., new scrap recovery accounts for about 57% of scrap recovery, while old scrap accounts for the remaining 43% (Jolly et al. 1993).

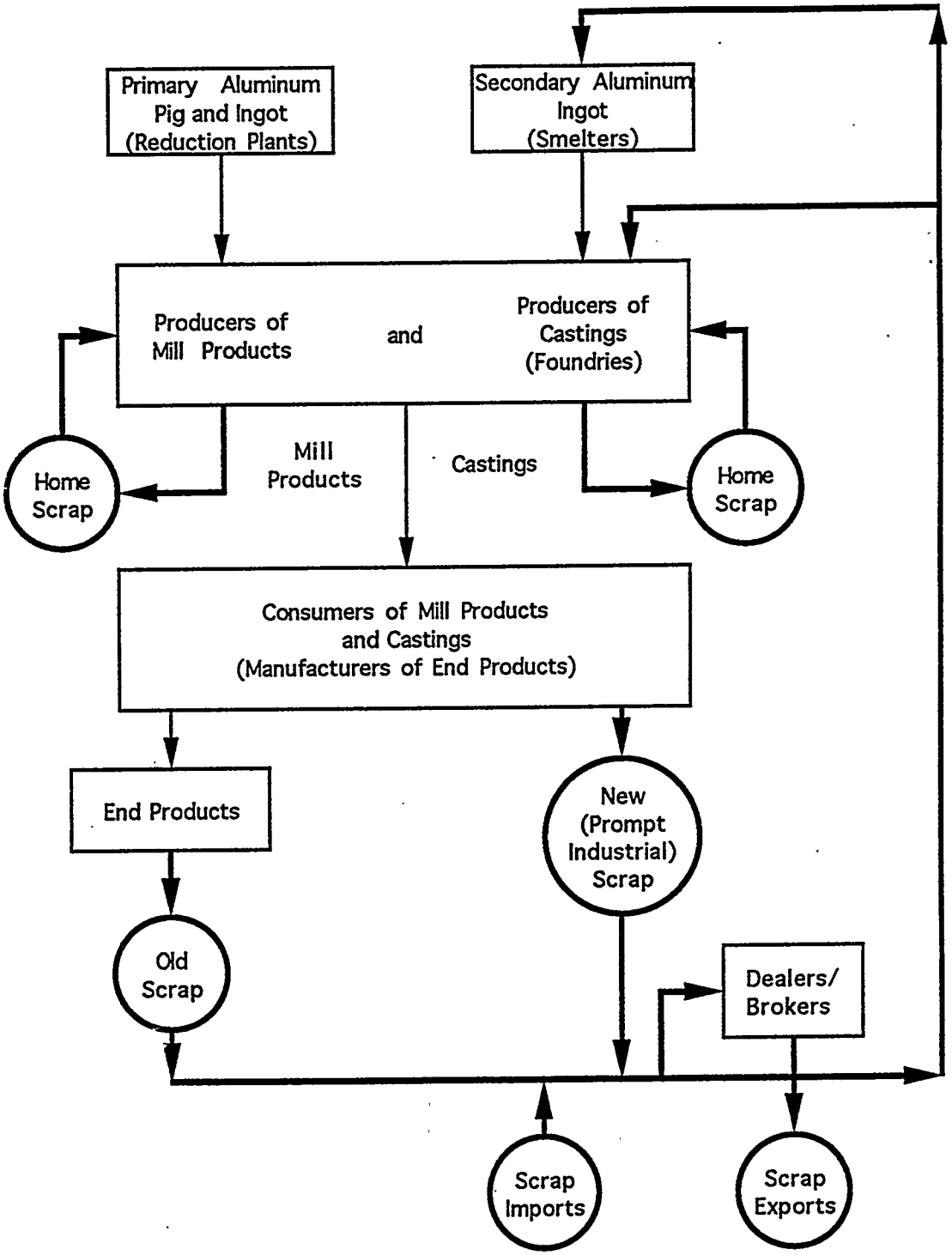


FIGURE 4.5 Aluminum Scrap Flow Diagram (Source: Based on U.S. Bureau of Mines 1985)

TABLE 4.2 Domestic U.S.A. Consumption of Old and New Aluminum Scrap, 1989-1990

	Consumption (10^3 t)		
Industry Segment	1989	1990	1991
Secondary smelters	805.0	982.0	1,080.1
Primary producers	1,027.5	1,212.4	1,260.8
Fabricators	222.5	238.3	237.2
Foundries	83.0	71.6	77.7
Chemical producers	36.0	57.0	31.0
Total industry	2,174.0	2,561.4	2,686.7

Sources: Jolly et al. (1993); Plunkert and Sehnke (1992).

Nickel

Nickel is recovered from four main types of scrap: ferrous-base, nickel-base, copper-base, and aluminum-base scrap. Ferrous-base nickel scrap is from stainless steel and constitutes by far the majority of nickel scrap. The stainless steel industry accounts for about 45% of nickel demand in the U.S.A. and more than 60% of world demand. In 1991, the U.S.A. recovered and consumed 32,520 tons of nickel from these four scrap categories, representing about 21% of total apparent nickel consumption for the year (Kuck 1993). Generally, stainless steel scrap is recycled to make stainless steel, nickel-bearing alloy scrap is recycled to make nickel-bearing alloys, and nickel-base superalloy scrap is recycled to make superalloys (Sibley 1985). Figure 4.7 illustrates the flow of nickel scrap through the recycling process.

Lead

In 1990, world secondary lead production is estimated at about 2,727.7 t, compared with primary production of 3,214 t. Therefore, 46% of world lead production was from secondary sources (Woodbury 1992). In the U.S.A., 70% of lead consumption was from scrap lead (Garino 1993). Battery production is by far the largest consumer of lead — about 80% of U.S.A. demand and 60% of world demand. Batteries also supply nearly 90% of lead scrap in the U.S.A. When lead scrap is collected, it must be smelted and refined at secondary plants in order to meet customer specifications. The smelting process typically generates a highly purified product containing more than 99% lead (Woodbury 1992). The lead scrap recycling process is illustrated in Figure 4.8.

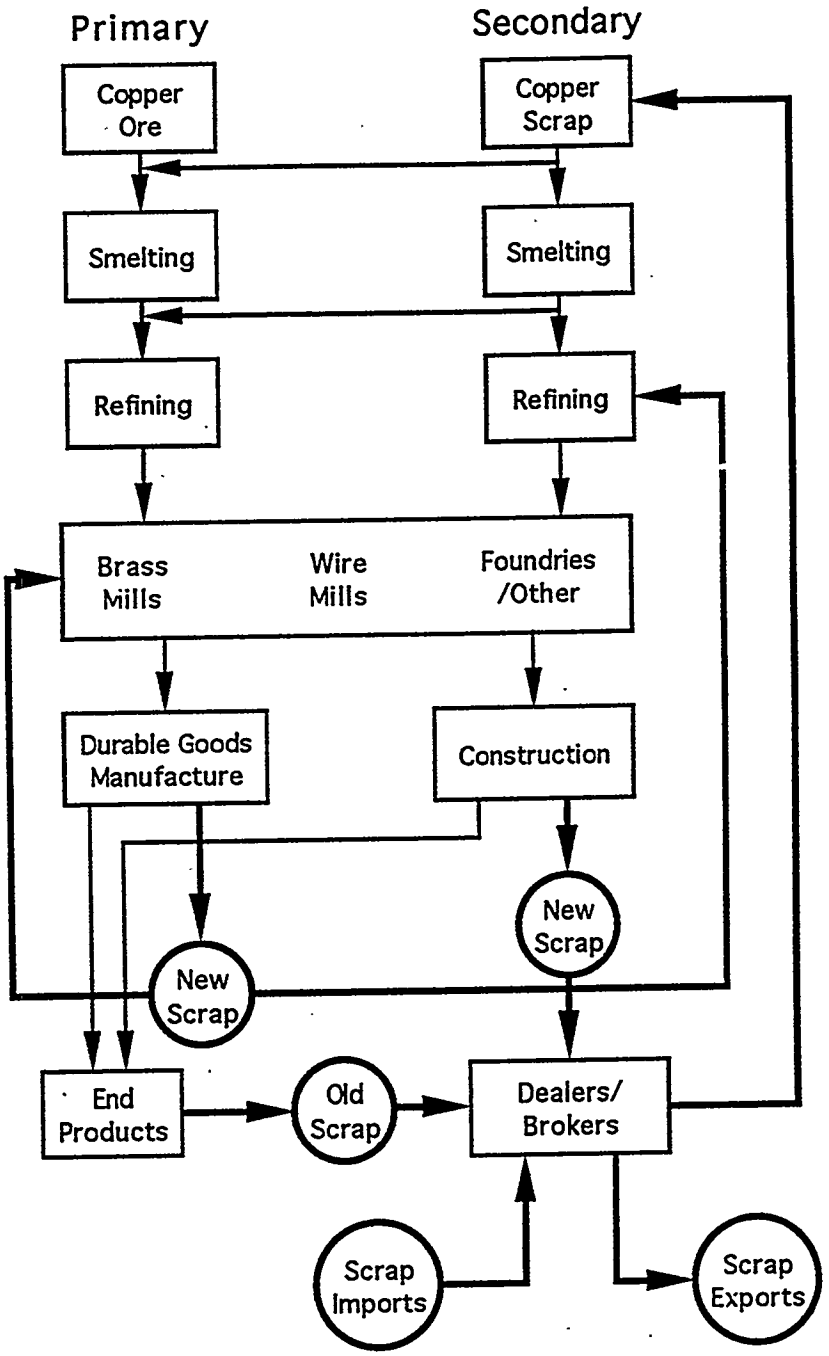


FIGURE 4.6 Copper Scrap Flow Diagram (excluding home scrap) (Source: Based on U.S. Bureau of Mines 1985)

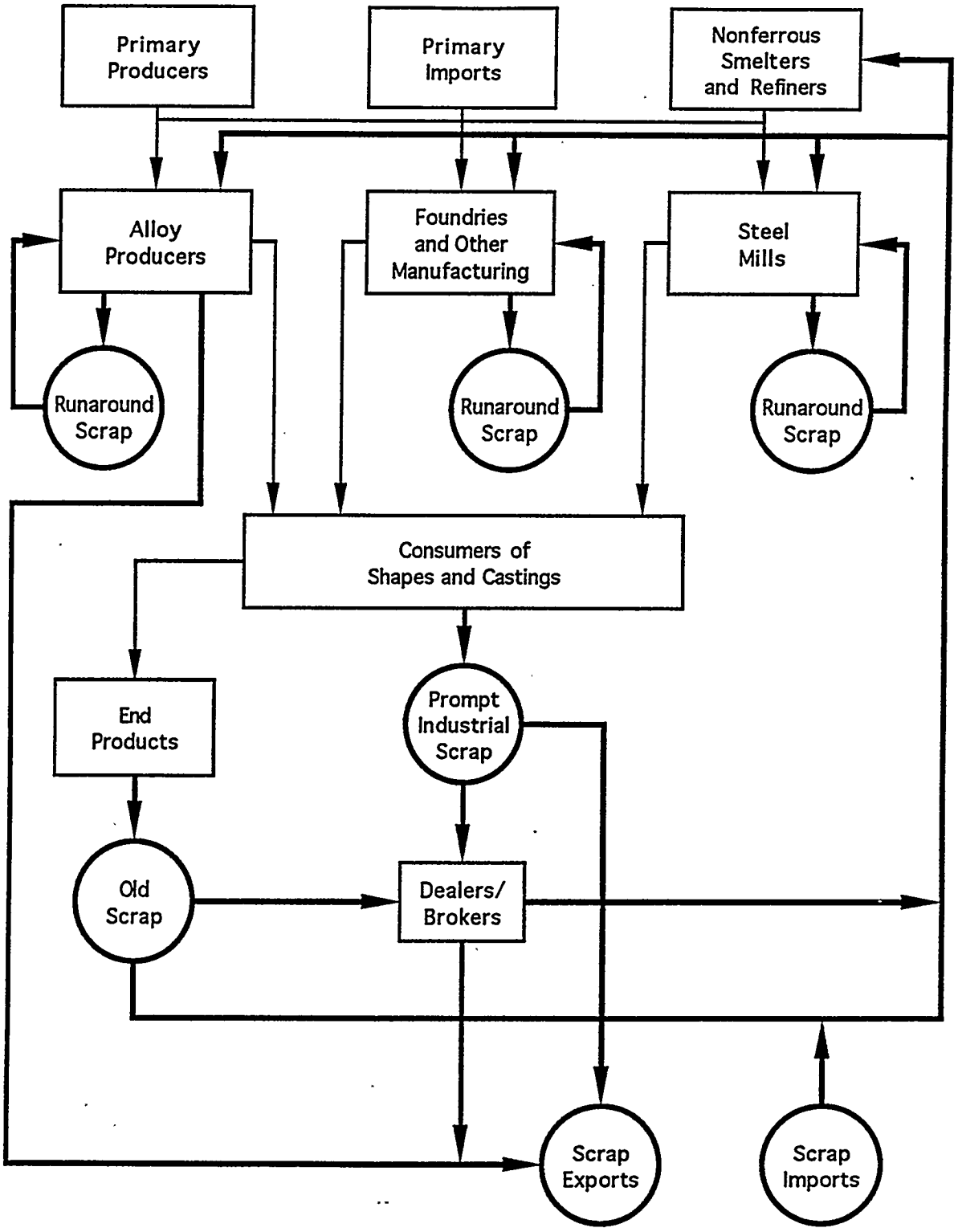


FIGURE 4.7 Nickel Scrap Flow Diagram (Source: Based on U.S. Bureau of Mines 1985)

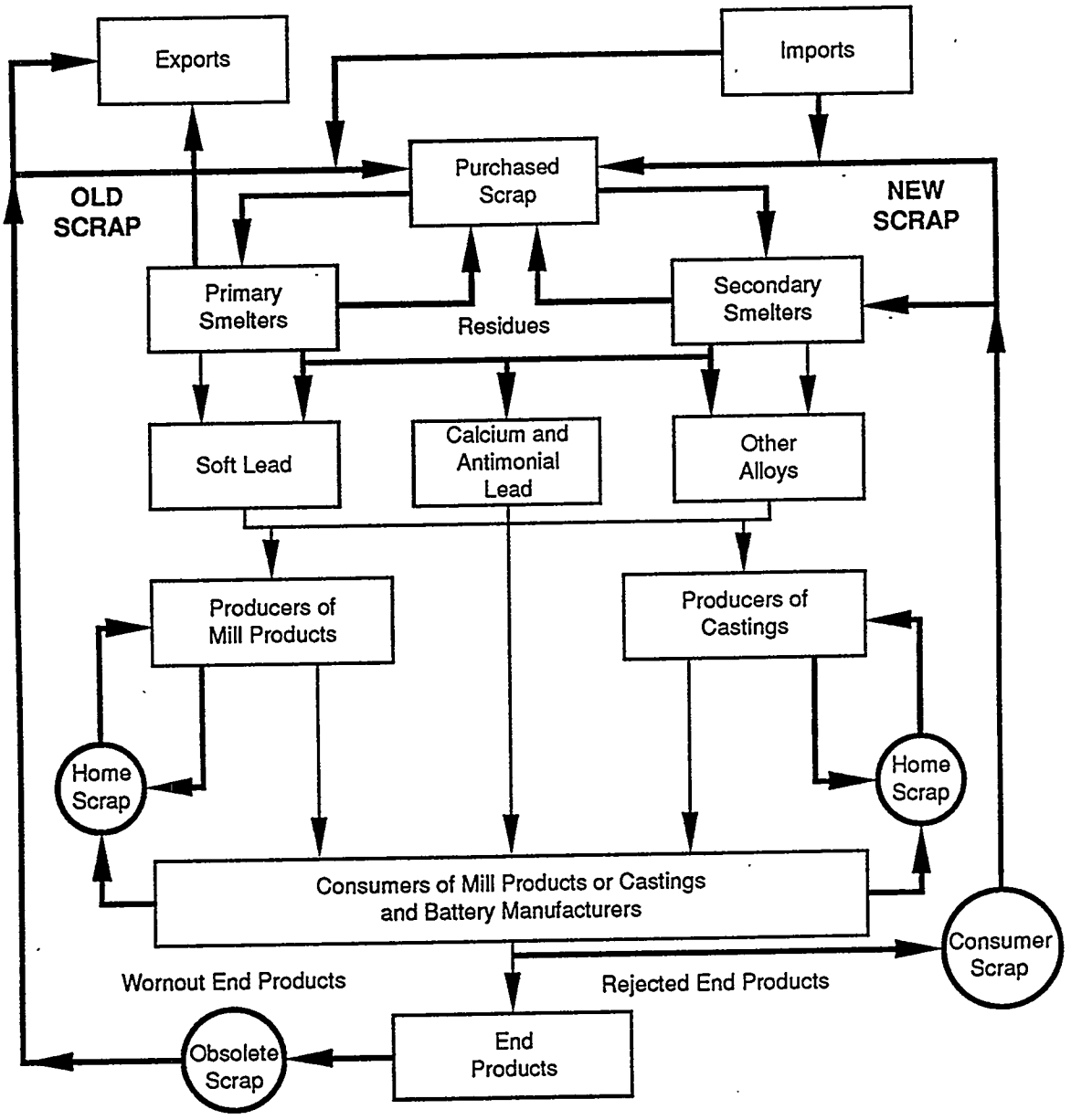


FIGURE 4.8 Lead Scrap Flow Diagram (Source: Based on U.S. Bureau of Mines 1985)

Zinc

World zinc production exceeded 7×10^6 t in 1991, while world zinc consumption was slightly less (Jolly 1992a). In 1991, scrap zinc accounted for 24% of zinc production in the U.S.A. (Garino 1993). The outlook for worldwide secondary zinc production is expected to remain strong as policies related to environmental and health protection continue to be implemented (Jolly 1992a).

In 1991, an estimated 450,000 t of zinc was recovered for recycle in the U.S.A. (Jolly 1992b). Figure 4.9 illustrates the zinc scrap recycling process. Zinc is recovered primarily

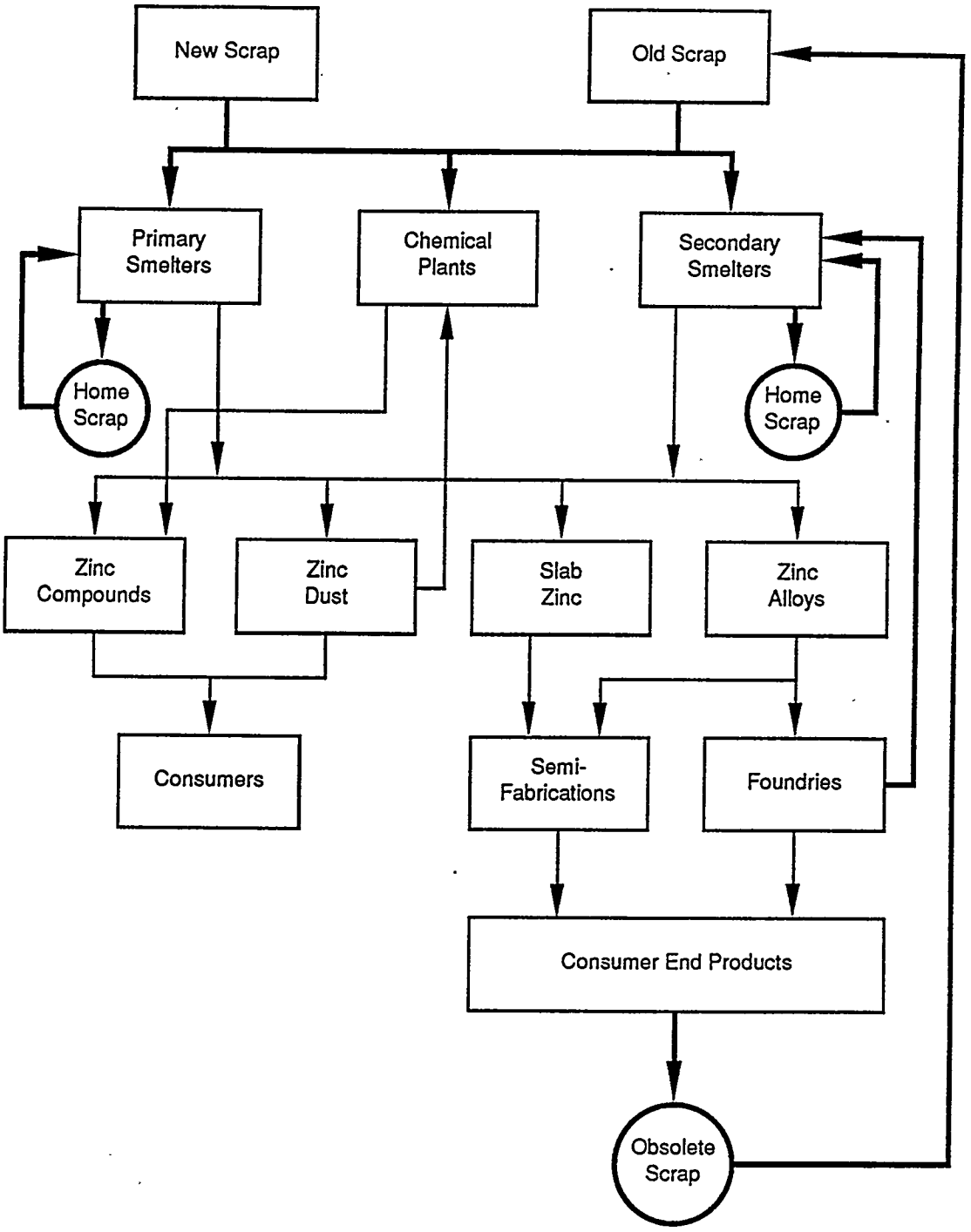


FIGURE 4.9 Zinc Scrap Flow Diagram (Source: Based on U.S. Bureau of Mines 1985)

from zinc-base and copper-base scrap, with small amounts originating from aluminum-base and magnesium-base scrap. Scrap is recycled in a secondary smelter, where it is separated into its zinc constituent and residue materials. Because zinc is so often combined with other metals, scrap recycled in secondary smelters cannot be sufficiently refined to produce a high-purity metal. Lead, iron, cadmium, aluminum, and tin are the principal metals contributing to the impurity of secondary zinc (Cotterill 1992). Another problem in zinc recycling is that the many dissipative uses of zinc (such as in galvanizing, paints, and rubber, for example) have restricted recovery of zinc from old scrap (Jolly 1985).

4.1.3.3 Ferrous/Nonferrous Slag

Slag is a by-product of metal refining that has a number of uses. Slag plays an important role in the smelting and refining process because it removes and separates impurities associated with the metals. In addition, slag forms a cover on the molten metal, protecting it from oxidation and contamination by impurities. After the production process, slag may be discarded or used in a variety of applications. The U.S. Bureau of Mines' *Dictionary of Mining, Mineral, and Related Terms* (Thrush et al. 1968) defines slag as: a substance formed in any one of several ways by chemical action and fusion at furnace operating temperatures:

- In smelting operations, through the combination of flux, such as limestone, with the waste portion of the ore;
- In the refining for metals, by substances such as lime added for the purpose of effecting or aiding the refining; or
- By chemical reaction between refractories and fluxing agents such as coal ash, or between two different types of refractories.

In 1991, about 25 $\times 10^6$ t of iron and steel slag, valued at \$130 $\times$ 10^6, was sold or used in the U.S.A. (Solomon 1992). About 69% of the total was iron slag, and the remainder was steel slag. Most of the slag was used in the construction industry. Road base consumed about 50% of the slag; asphaltic concrete aggregate, 14%; concrete aggregate, 11%; fill, 13%; and other, 12% (Table 4.3). In Germany, the primary uses are as fill material, 24%; and as ground covering, 19% (CEC 1995).

Copper slag has a number of uses, such as railroad ballast, aggregate for road beds, soil conditioners, slag wool, light-weight concrete cement-making, and (recently) mineral wool. Copper production yields approximately 4 t of slag per 1 t of copper. Slag from other metal smelting processes is usually landfilled.

4.2 INTERNATIONAL SCRAP METAL TRADE

This section discusses some of the broader economic factors that shape international trade in scrap metals. The discussion begins with a brief overview of some of the factors and

TABLE 4.3 Principal Uses of Blast-Furnace Slag

Type	Principal Uses		
Air cooled, crushed and screened slag	Ballast, railroad Concrete, portland cement Concrete units: masonry hollow Binder course, sheet asphalt pavement Bituminous concrete base or surface course Bituminous macadam base or surface course Bituminous surface treatment	Cushion course for brick or block pavement Sand for sheet asphalt or bituminous concrete Waterbound base or wearing course Sewage trickle-filter media Roofing granules, bituminous built-up roofing, Mineral wool Subbases and special subgrade insulations	Traffic bound roads, berms, shoulders Stabilized roads and bases Porous backfill and underdrains Lightweight aggregate expanded slag Embankments, roadwalk fills, bank slag Glass sand, ceramic ware
Granulated slag	Portland cement Slag cements Soil corrective agricultural slag	Roadway insulation courses Special subgrade and subbases Ceramic ware glass sand	Roadway fills and embankments Concrete units Building blocks
Expanded slag	Concrete masonry units Structural concrete Fireproofing Floor tile	Precast products Floor joints and slabs Building blocks Brick	Acoustical tile Curtain walls: Back up insulation Fire resistive

Source: McGannon (1971).

trends that shape the scrap metal market. Then, factors affecting the supply and demand for scrap metal are discussed. Trade flows between geographic regions (Europe, North America, Asia, and others) are then examined. The section closes with analysis of recent trends in scrap metal prices.

4.2.1 Overview

In 1990, the international scrap metal trade totaled between \$11.0 and 12.8×10^9 (U.S.A. dollars) (United Nations 1992).[2] Ferrous scrap accounted for 44% of the total value of scrap traded and nonferrous accounted for 56%. International scrap trade occurs primarily between industrialized countries, but developing countries with emerging metal refining and fabricating capability may have significant trade (import) volumes. Recent analysis of iron and steel scrap trade data reveals a trend for scrap to flow from north to south — from industrialized to developing countries — as developing countries build up their domestic steel industries. Although international scrap trade usually involves processed scrap, it can include raw scrap. Processed scrap metals are freely traded commodities much like grains, precious metals, oil, or currencies. Unlike other commodities, however, no centralized trading place exists for scrap metal.[3] Rather, scrap is bought and sold via telephone or face-to-face negotiations between dealer/processors, brokers, and mill/foundry operators.

When scrap dealers negotiate prices, published prices are used as a benchmark or starting point. International scrap prices also depend on several other factors, such as local demand, logistics (transportation costs, timing, etc.), quality (grade), exchange rates, and trade barriers (if applicable). For example, the high transportation cost associated with scrap tends to segment markets geographically. In the U.S.A., prices are quoted for Pittsburgh, Philadelphia, Chicago, Cleveland, St. Louis, Birmingham, and other cities, and these prices tend to reflect regional (local) supply and demand relationships.

4.2.2 Scrap Metal Supply and Demand

Home scrap has in the past been a significant source of scrap. Newer, more efficient technologies have reduced the quantity of home scrap generated and have reduced its importance. To offset the reduced supply of home scrap, steel fabricators are using more purchased scrap. During periods of weak domestic and international demand, most purchased scrap will be industrial scrap. Industrial scrap quantity is determined by the quality and level of manufacturing production. As manufacturing activity increases, so does the quantity of industrial scrap that is generated.

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[2] The range of values reflects different import and export totals, which should be equal to each other. This discrepancy is caused in part by different data collection practices for the various countries.

[3] Refined metals are traded in centralized markets, such as the New York Commodities Exchange or the London Metals Exchange.

In contrast, obsolete scrap is a "swing" product. Demand for obsolete scrap depends on the difference between total market demand for scrap and the quantity of industrial scrap available. In weak markets, industrial scrap may meet all of the demand for scrap, with the demand for obsolete scrap falling to nothing. In high demand periods, the demand for obsolete scrap increases as the supply of industrial scrap is consumed (Institute of Scrap Iron and Steel 1984). Thus, business fluctuations in the metals industry are greatly magnified for those handling obsolete scrap.

Given the present competitiveness of the world markets, the stability of scrap supply to manufacturers and refiners is critical. Business conditions today dictate that suppliers be able to consistently deliver quality product in a timely fashion on short notice. Thus, suppliers must anticipate business trade and maintain an adequate inventory at all times. In addition, scrap processors must pay adequate prices to the suppliers (collectors, metal fabricators, etc.) to support these sources during periods of weak demand. Thus, purchasing decisions of scrap buyers (traders) must factor in both short-term and long-term demand considerations.

To help ensure a continuous supply of scrap, many processors use forward contracts. A forward contract is an agreement for delivery of a specified quantity of scrap of a specified type at a specified time in the future (typical contract lengths are one, three, and six months) for a price agreed on today. Forward pricing is based upon expected future prices. Forward contracts have become prevalent with manufacturers/processors (such as Alcoa) and brokers/traders from whom manufacturers/processors purchase scrap. This practice helps ensure scrap supply into the future.

A common saying in the scrap metal industry is: "Scrap is bought, not sold." This reflects the fact that demand for scrap is almost wholly derived from the demand for the refined metal smelted from the scrap. Two other factors that influence the demand for scrap are the price of metal smelted from ore and the purity of the scrap. As the price of smelting metal from ore increases, the value of scrap goes up because it is relatively cheaper to refine from scrap. Similarly, if the scrap is relatively pure (i.e., free of tramp elements) then the scrap has greater value because it requires little or no refining.

The primary use of ferrous scrap continues to be in steel-making activities. Estimated world scrap consumption in 1989 was 388.5×10^6 t. The largest scrap consumer was Eastern Europe with 119×10^6 t (or 31%), followed by Western Europe with 82×10^6 t. The U.S.A. consumed 66×10^6 t. More than about 50% of all steel manufactured in the U.S.A. is made of scrap (Institute of Scrap Recycling Industries 1990). End uses of the commodity metals in the U.S.A. are listed in Table 4.4.

As environmental concerns become more prevalent worldwide, the recovery and use of scrap are likely to experience strong growth through the 21st century. Between 1983 and 1990, ferrous scrap recovery and use in the U.S.A. grew around 2% annually, while Japan experienced a growth rate of 3% a year. As electric furnace use increases worldwide, so too will scrap consumption.

TABLE 4.4 Domestic U.S.A. End Uses of Commodity Metals

Commodity	Use	Percent Consumption
Aluminum	Packaging	33
	Transportation	20
	Building	19
	Electrical	9
	Consumer	8
	Other uses	11
Copper	Building/construction	40
	Electrical	26
	Industrial machinery and equipment	14
	Consumer and general products	9
Iron and Steel	Warehouses and steel service centers	21
	Transportation	11
	Construction	11
	Cans and containers	6
	Other uses	51
Lead	Transportation (batteries)	75
	Other uses	25
Nickel	Transportation	26
	Chemicals	12
	Electrical equipment	8
	Construction	8
	Fabricated metals	7
	Machinery	6
	Household appliances	6
	Petroleum	5
	Other uses	22
Zinc	Construction materials	46
	Transportation	20
	Machinery	11
	Electrical	11
	Other uses	12

Source: U.S. Department of the Interior (1992).

4.2.3 Metal Trade Profiles

Each of the scrap metals discussed in this study is traded internationally, and these global trading patterns are discussed here. Figure 4.10 shows the levels of 1989 international scrap shipments for the metals of interest. Iron and steel scrap has the greatest international trade volume (42×10^6 t) and nickel scrap has the least (0.03×10^6 t).

The data presented in this section represent transboundary shipments, not the domestic consumption for each country. Domestic consumption data would be more relevant because scrap metal markets are primarily regional. High transportation costs discourage transboundary shipments. Therefore, the data presented here will tend to underestimate global scrap metal activity. However, domestic consumption data were not readily available except for U.S.A. markets and for iron and steel scrap. One generalization can be made: larger market volumes facilitate trade. Thus, it should be easier to sell iron and steel scrap than, say, lead or zinc scrap.[4]

Furthermore, the data should be interpreted cautiously since there is evidence of data error in the fact that the world total exports do not equal total imports. This discrepancy may be attributed in part to unreported or inconsistent data from individual scrap dealers and brokers and metal manufacturing industries (Kauffmann 1993). As a consequence, world trade volumes are presented as an average of import and export totals, although regional and country data are presented as reported. Market shares are approximated to the nearest 5% increment.

4.2.3.1 Iron and Steel Scrap

As presented in Table 4.5, world iron and steel scrap trade increased significantly between 1985 and 1989. In 1989, the largest scrap exporting regions were North America (50%) and Europe (almost 50%). The remaining regions contributed relatively insignificant export volumes. By a wide margin, the U.S.A. was the largest single exporter (50%), followed by the former West Germany (10%) and France (10%). Europe was the largest importer of scrap, accounting for 50% of world imports; followed by Asia at (45%); and North America at 5%. The largest single country importers were Italy (15%), Spain (10%), Turkey (10%), and South Korea (10%). Japan, a major user of iron and steel for automobiles, imported little because most of their scrap needs are met internally.

4.2.3.2 Aluminum Scrap

Table 4.6 presents the international scrap aluminum trade volume by region. Between 1985 and 1989, world trade increased more than 50%. In 1989, Europe was the largest exporting region at around 50% of world exports. North America followed with about

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[4] Nickel is a special case since it is used so commonly as an alloying element.

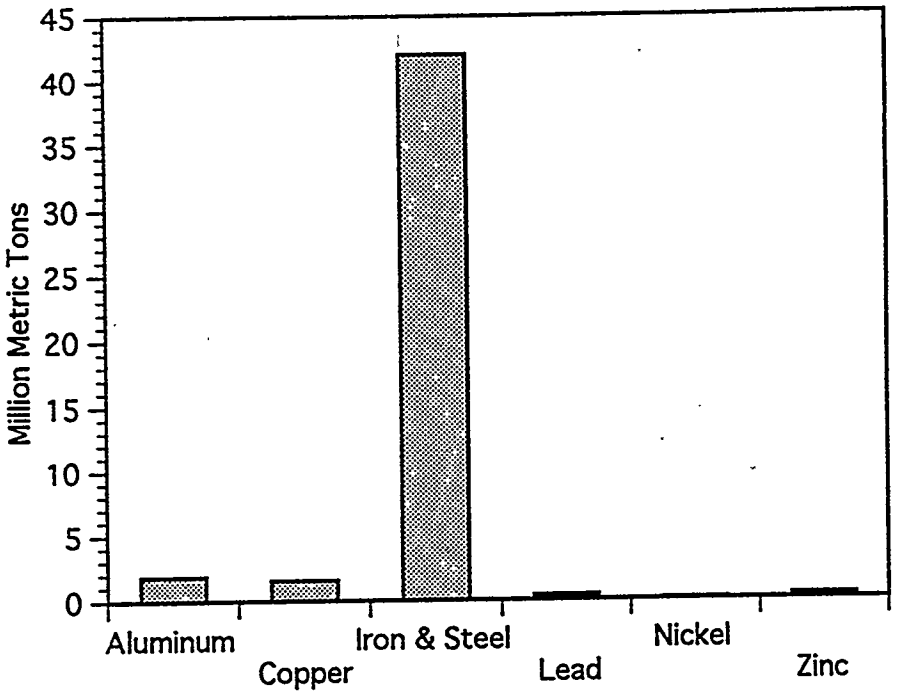


FIGURE 4.10 1989 International Scrap Trade

TABLE 4.5 International Scrap Iron and Steel Trade (in 10^3 t)

Continent and Country Group	Exports		Imports	
	1985	1989	1985	1989
North America	9,985	22,082	1,429	2,476
Latin America	85	0	1,672	259
Europe				
European Community	15,041	16,799	16,733	16,489
European Free Trade Association	179	329	1,488	960
Council for Mutual Economic Assistance	3,625	3,529	1,011	1,070
Other	185	239	729	646
Total Europe	19,030	20,896	19,960	19,166
Africa	325	78	16	3
Asia	1,482	1,730	10,423	16,615
Oceania	489	987	4	2
World Total	31,395	45,773	33,505	38,521

Source: British Geological Survey (1991).

TABLE 4.6 International Scrap Aluminum Trade (in 10^3 t)

Continent and Country Group	Exports		Imports	
	1985	1989	1985	1989
North America	491	740	181	265
Latin America	5	2	1	3
Europe				
European Community	438	708	558	912/
European Free Trade Association	71	140	90	133
Council for Mutual Economic Assistance	41	53	0	0
Other	–[a]	1	0	0
Total Europe	550	903	648	1,045
Africa	9	2	1	–
Asia	71	126	392	557
Oceania	21	8	3	0
World Total	1,147	1,782	1,225	1,870

[a] – denotes less than 10^3 t.

Source: British Geological Survey (1991).

40% of world exports. The U.S.A. exported 30% of the world trade and was the largest single country exporter, followed by the former West Germany and Canada (at 10% each). Europe was the largest importing region with 50% of world imports, followed by Asia at 30%. The largest single country importers in 1989 were Japan at 20%, the former West Germany at 15%, and the U.S.A. at 10%.

4.2.3.3 Copper Scrap

Table 4.7 indicates that smaller volume increases occurred in the international copper scrap trade than in aluminum trade. Copper trade volume over the 1985-1989 period increased approximately 35% worldwide. In 1989, Europe accounted for 40% of world exports followed by North America at 30%. The largest exporter was the U.S.A., accounting for 25% of world exports, followed by France at 15%. Europe led all importers with 60%, and Asia was next at 20%. The largest single importers were the former West Germany with 20% of world imports and Belgium at 10%.

TABLE 4.7 International Scrap Copper Trade (in 10^3 t)

Continent and Country Group	Exports		Imports	
	1985	1989	1985	1989
North America	345	437	140	208
Latin America	4	2	99	49
Europe				
European Community	457	713	689	950
European Free Trade Association	44	68	72	51
Council for Mutual Economic Assistance	40	29	33	32
Other	2	2	1	1
Total Europe	544	812	794	1,033
Africa	23	13	1	2
Asia	128	196	192	367
Oceania	2	3	1	0
World Total	1,049	1,462	1,228	1,659

Source: British Geological Survey (1991).

4.2.3.4 Lead Scrap

Table 4.8 indicates the relatively small volume of international trade in scrap lead. Exports increased more than 15% over the 1985-1989 period. The largest exporting regions were Europe (55%) and North America (25%). The largest exporting countries were the U.S.A. (20%) and the United Kingdom (10%). The largest importing regions were Asia and Europe at about 45% of imports each. The largest importing countries were Taiwan (20%), Korea (10%), France (10%), and the former West Germany (10%). Unlike most scrap metals, which have experienced growth over the last 20 years, lead production over the 1970-1990 period remained relatively constant. This condition may, in part, be attributed to two primary factors: (1) legislation calling for the reduction or elimination of some end uses of lead (and therefore of scrap) and (2) the continued reductions in lead use per battery and in ammunition (Woodbury 1992). Evidence indicates that the reduced demand for lead scrap experienced in the U.S.A. is likely to occur in the international markets as well.

TABLE 4.8 International Scrap Lead Trade (in 10^3 t)

Continent and Country Group	Exports		Imports	
	1985	1989	1985	1989
North America	71	68	46	38
Latin America	2	0	1	0
Europe				
European Community	107	115	128	131
European Free Trade Association	18	41	27	20
Council for Mutual Economic Assistance	3	1	8	11
Other	0	0	1	3
Total Europe	128	157	163	166
Africa	2	1	17	2
Asia	17	55	108	167
Oceania	19	0	0	0
World Total	239	281	336	372

Source: British Geological Survey (1991).

4.2.3.5 Nickel Scrap

Table 4.9 indicates trends in world nickel trade, which has increased over the 1985-1989 period. Europe with 50% of world exports and North America with 40% were the largest exporting regions. The largest country exporters were the U.S.A. at 30%, the former West Germany at 15%, and Canada at 15%. With 60% of word imports, Europe was the world's largest importing region by a significant margin. North America followed with 35%. Canada was the largest importing country at 20%; the former West Germany was second at 20%; and Sweden was third at 15%.

Because of nickel's widespread uses in industrial and consumer product applications, such as stainless steels, production (and the consumption of scrap) has increased significantly. Over the period 1950-1990, production increased about 600%, an annual growth rate of about 4.6%.

TABLE 4.9 International Scrap Nickel Trade (in 10^3 t)

Continent and Country Group	Exports		Imports	
	1985	1989	1985	1989
North America	19	23	5	24
Latin America	0	0	0	0
Europe				
European Community	24	26	16	26
European Free Trade Association	3	1	9	17
Council for Mutual Economic Assistance	0	0	0	0
Other	–[a]	0	0	0
Total Europe	27	27	25	43
Africa	–	1	0	0
Asia	3	4	5	4
World Total	50	54	35	71

[a] – denotes less than 10^3 t.

Source: British Geological Survey (1991).

4.2.3.6 Zinc Scrap

As indicated in Table 4.10, zinc trade increased between 1985 and 1989. Major exporting regions were Europe at 55% of world exports and North America at 35%. The largest exporting counties were the U.S.A. (35%), followed by the United Kingdom (10%), the Netherlands (10%), and the former West Germany (10%). The major importing region in 1989 was Asia with 65% of world imports, followed by Europe at 35%. The largest importing countries were Taiwan (60%), the former West Germany (10%), and Belgium (5%). The remaining imports went primarily to other European countries.

4.2.4 Recent Trends in Scrap Prices

This section examines price trends of scrap metals from 1987 through early 1993. Monthly average price data for each scrap metal are graphed from bid quote data published

TABLE 4.10 International Scrap Zinc Trade (in 10^3 t)

Continent and Country Group	Exports		Imports	
	1985	1989	1985	1989
North America	57	109	3	11
Latin America	0	0	0	0
Europe				
European Community	77	151	62	89
European Free Trade Association	6	15	–[a]	1
Council for Mutual Economic Assistance	4	2	0	0
Other	0	0	0	0
Total Europe	7	168	62	90
Africa	0	0	–	–
Asia	12	16	36	172
Oceania	1	1	0	0
World Total	157	295	101	273

[a] – denotes less than 10^3 t.

Source: British Geological Survey (1991).

in *Metal Statistics 1993* and in the June 1993 daily issues of *American Metal Market*.[5] These time series share a few features: (1) many of the scrap prices peaked in the late 1980s and then again in the early 1990s before trending downward through the remainder of the period; (2) the prices are volatile; and (3) the grades maintain their relative price relationships within metal type. The time series graphs are discussed below in more retail.

4.2.4.1 Iron and Steel

Figure 4.11 presents prices for three grades of scrap iron and steel. The grades presented — No. 1 heavy melting, No. 2 heavy melting, and plate and structural — are most likely to be comparable to RSM characteristics. Several features of this figure are notable: prices display no consistent trend; they are fairly volatile; the spread between grades varies

[5] The bid quote is used (rather than the ask quote) because in the scrap metal market the buyer sets the price, not the seller.

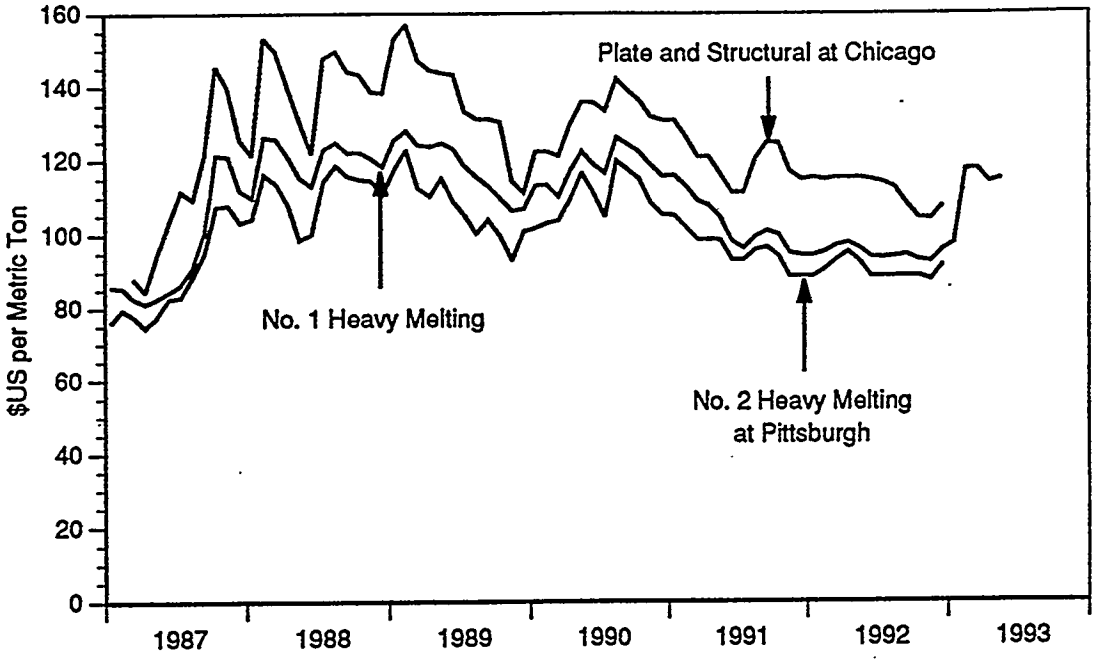


FIGURE 4.11 U.S.A. Scrap Iron and Steel Prices (Sources: 1987-1992 prices from American Metal Market Co. 1993a; 1993 prices based on June 1993 issues of *American Metal Markets* [American Metal Market Co. 1993b])

overtime, which indicates that the markets differ somewhat for different grades of scrap; and the three grades maintain their relative price relationships (i.e., plate and structural always has the highest price and No. 2 heavy melting has the lowest price). Prices increased early in the time period, peaking in February 1989 before declining unsteadily through 1992. Within one year, prices declined an average of more than 20%, but scrap prices were relatively more volatile in the earlier part of the period.

4.2.4.2 Stainless Steel

Figure 4.12 presents the stainless steel scrap time series. Stainless scrap prices peaked dramatically in early 1989, increasing from $529.40 per ton in February 1987 to $1,839.18 per ton in March 1989. This change represented an increase of 247% over the 25-month period. Less than one year later, however, prices had fallen to $786.41, a decrease of more than 57% from the peak. Prices rebounded through 1990, but a downward trend has occurred since mid-1990. As of December 1992, scrap stainless steel prices were about $702.72 per ton.

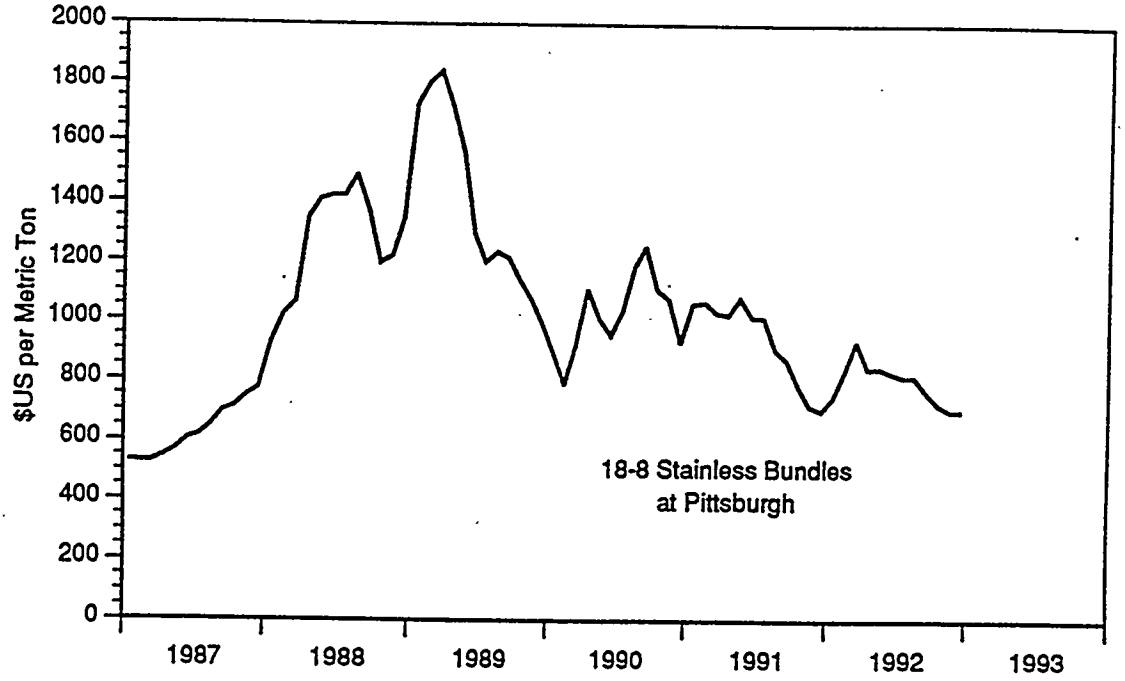


FIGURE 4.12 U.S.A. Scrap Stainless Steel Prices (Source: Based on prices from American Metal Market Co. 1993a)

4.2.4.3 Aluminum

Figure 4.13 presents the price time series for old sheet and cast aluminum scrap. Aluminum scrap prices peaked in mid-1988, almost a year earlier than ferrous scrap, at $1,497.60 and $1,226.65 per ton for retail and wholesale,[6] respectively. Like ferrous scrap, aluminum scrap prices dropped through early 1990 before rebounding in mid-1990. Prices then fell unsteadily through mid- and late 1991, bottoming at $747.37 per ton in June 1991 for retail old sheet and cast and $396.38 per ton in December 1991 for wholesale old sheet and cast scrap. From mid-1988 to early 1990, scrap aluminum prices fell an average of 44% from their highs, and from April 1988 to December 1991, wholesale scrap prices fell to less than one third of the 1988 high.

4.2.4.4 Copper

Copper scrap prices displayed less volatility than prices for the metals discussed above, but the time series followed the same trends (Figure 4.14). Prices peaked in April 1989 at $2,445.58 per ton for retail and $2,115.33 per ton for wholesale No. 2 copper

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[6] Retail prices are those paid by smelters and other scrap consumers. Wholesale prices are the prices paid by dealers who then resell the scrap to consumers.

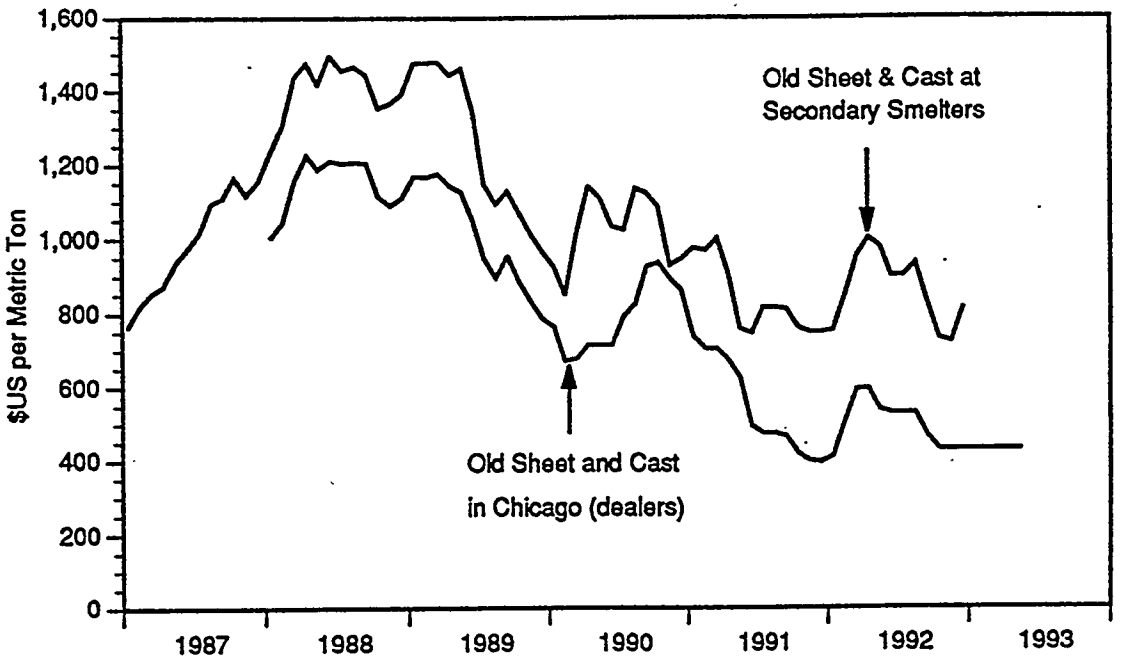


FIGURE 4.13 U.S.A. Scrap Aluminum Prices (Source: 1987-1992 prices from American Metal Market Co. 1993a, 1993 prices based on June 1993 issues of *American Metal Markets* [American Metal Markets Co. 1993b])

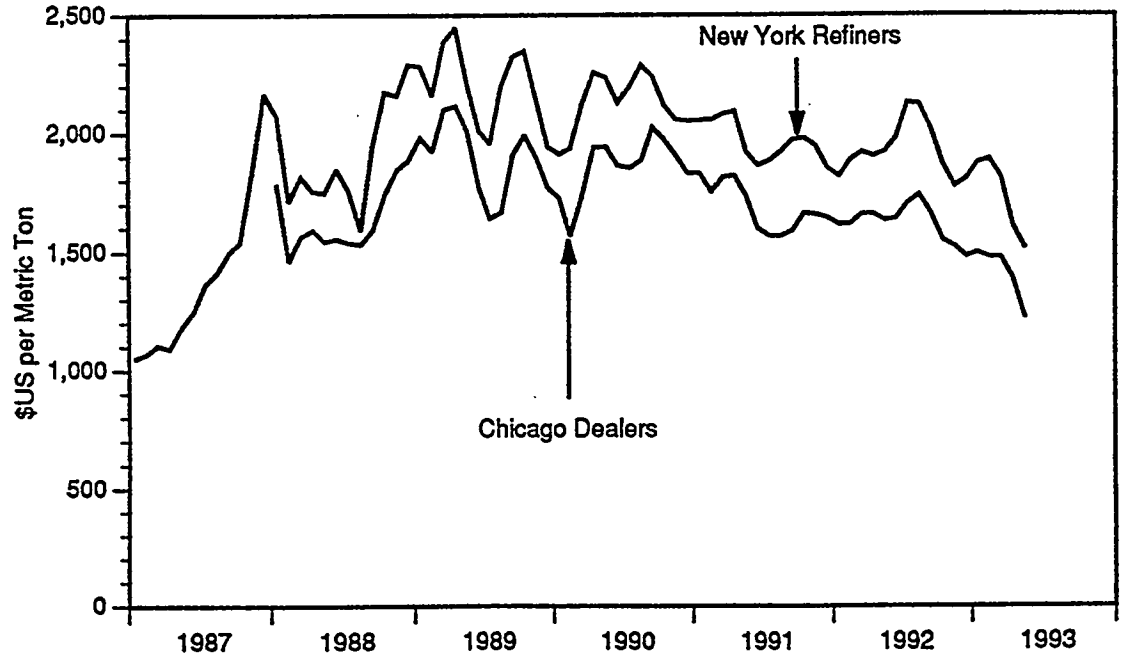


FIGURE 4.14 U.S.A. Scrap No. 2 Copper Prices (Sources: 1987-1992 prices from American Metal Market Co. 1993a; 1993 prices based on June 1993 issues of *American Metal Markets* [American Metal Market Co. 1993b])

scrap. Less than 12 months later, prices had fallen to $1,990.52 and $1,565.25 per ton, respectively, for an average decline of 22%. Prices recovered through 1990 and then declined over the remainder of the period. Prices rallied somewhat in mid-1992, but did not reach 1990 prices. Since that period, however, prices have fallen almost 30%.

4.2.4.5 Lead

As shown in Figure 4.15, lead prices did not follow the same pattern as other metals, but instead displayed a large degree of variability with an overall downward trend. Midwest heavy soft lead prices peaked in late 1988 at $429.90 per ton and again in mid-1990 at $440.92 per ton, but then fell to $242.51 in mid-1991. The price then remained relatively constant through the end of the period.

4.2.4.6 Nickel

Nickel scrap prices are not as widely quoted as those for the other metals, but a scrap price trend may be inferred from the price history for the refined metal. Prices for refined nickel (99.9% pure) reached a high the week of September 10, 1990, at $11,927 per ton. Prices have since fallen, reaching a new low of $4,586 per ton on August 18, 1993. The downward price trend has been caused by excess supply in the market. Traders cite selling by countries in the former Soviet Union as the primary source of new metal in the market. Nickel scrap trades at a discount to the refined metal price, and the discount may range from 5% to 75%, with higher-grade, higher-quality scrap selling at a lesser discount. As of August 20, 1993, these discounts indicated a scrap nickel price range of $1,200 to $4,460 per ton (Kolb 1993).

4.2.4.7 Zinc

Prices for old zinc scrap peaked at $559.31 per ton in early 1989 and then again at $584.22 per ton in late 1990 and early 1991 (Figure 4.16). Prices fell more than 20% in two months to $462.97 in mid-1991 and have remained constant since then. The trend of steady prices is caused by the same market forces that affect the scrap lead industry. A reduction in the number of secondary zinc smelters has reduced competition within the industry, allowing scrap buyers to lock in prices on long-term contracts.

4.3 CURRENT INDUSTRY PRACTICE FOR PROCESSING CONTAMINATED SCRAP

Scrap yards, mills, and foundries must cope with a variety of contaminants in the metals they recycle. For example, lubricating oils and fluids and process acids may be left on the scrap. In most cases, process acids are neutralized before the processor handles the

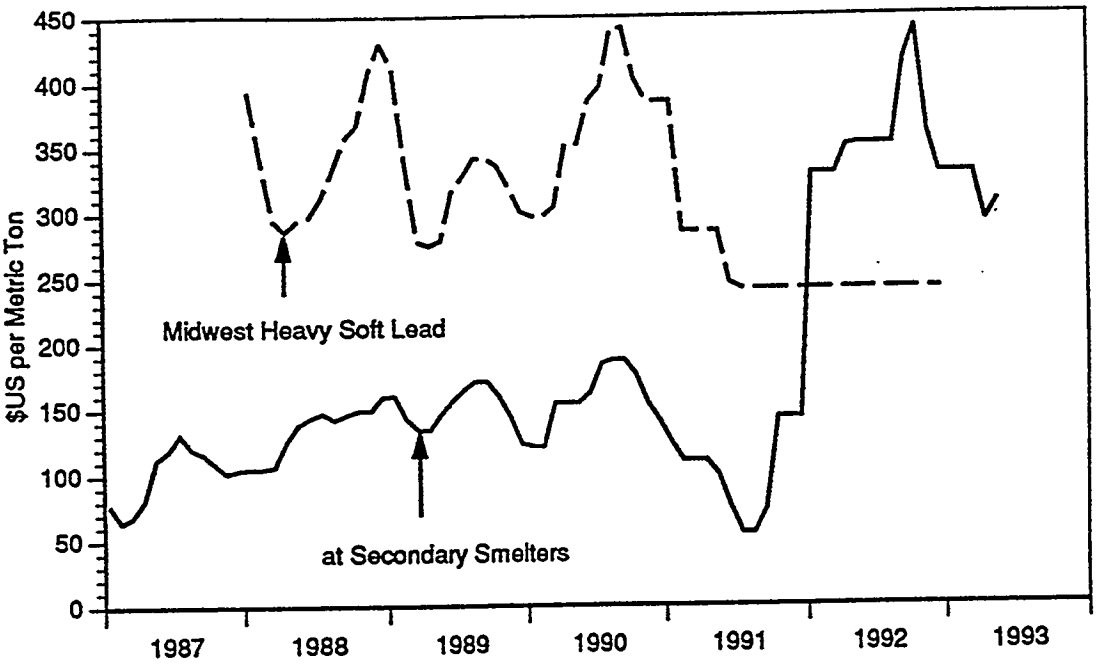


FIGURE 4.15 U.S.A. Scrap Lead Prices (Sources: 1987-1992 prices from American Metal Market Co. 1993a; 1993 prices based on June 1993 issues of *American Metal Markets* [American Metal Market Co. 1993b])

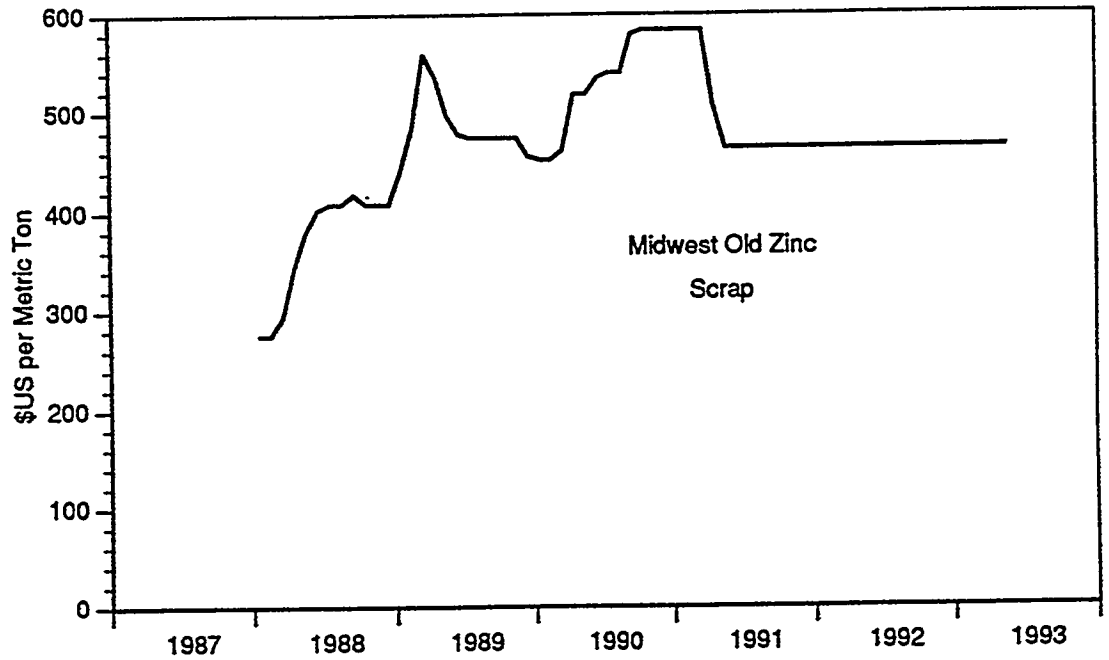


FIGURE 4.16 U.S.A. Scrap Zinc Prices (Sources: 1987-1992 prices from American Metal Market Co. 1993a; 1993 prices based on June 1993 issues of *American Metal Markets* [American Metal Market Co. 1993b])

scrap. Lubricating oils and fluids can be more of a problem to the scrap processor, because they can wash off or leach from scrap storage piles to contaminate the soil. Scrap contaminated with a significant quantity of these fluids is less desirable to scrap buyers, so it is downgraded in quality and price. When the scrap is melted, some elements in the oils may remain in the molten metal mixture, but usually only in insignificant quantities. These residues usually have minimal impact on the refined metal.

For hazardous chemicals, such as polychlorinated biphenyls (PCBs), the preferred solution is to avoid purchasing and processing contaminated scrap. This solution is accomplished by monitoring the scrap coming into the yard, by knowing the source of the scrap, and by rejecting any scrap that has even the potential to be contaminated. If the metal is obsolete scrap, the scrap processor must rely largely on the reputation of the scrap collector, because it is relatively easy to hide or mask substandard or contaminated materials in a large shipment. Competition in the industry is sufficient to quickly drive processors and dealers with poor reputations to bankruptcy. The remainder of this section discusses how the recycling industry deals with radioactivity in scrap.

4.3.1 Sources of Radioactive Material in Scrap Metal

Radioactive contamination of scrap metal is not a new phenomenon. The first well-publicized incident in the U.S.A of smelting scrap containing radioactive materials occurred in 1983 at the Auburn Steel Company mill in New York (Lubenau and Yusko 1990). A major international incident occurred in 1984 in which Co-60 pellets from a medical teletherapy device were melted at a foundry in Mexico. The contaminated metal was used to make cast iron table legs and concrete reinforcing bars, some of which were then exported to the U.S.A. Other incidents have been reported around the world, but currently no comprehensive data exist for the extent of radioactive contamination in metal.

Figure 4.17 graphs the number of incidents worldwide since 1983 (tracked by Lubenau and Yusko 1995) in which radioactive materials were found in scrap or in the by-products after smelting (slag or flue dust). This information is from an informal database begun in the late 1980s. The upward trend is probably exaggerated because data is sparse for earlier years. In addition, the increase in incidents later in the period is probably caused by a greater number of detection systems installed at scrap yards and metal mills and foundries. As incomplete as the information is, however, it demonstrates that a problem with radioactive scrap metal exists. The database lists 315 incidents, 35 of which involved smelting. Figure 4.18 illustrates the relative frequency with which each type of radioactive material was found. Naturally occurring radioactive materials (including radium, uranium, and thorium) account for more than half of the incidents, and the radioactive material type is unknown in 26% of the incidents.

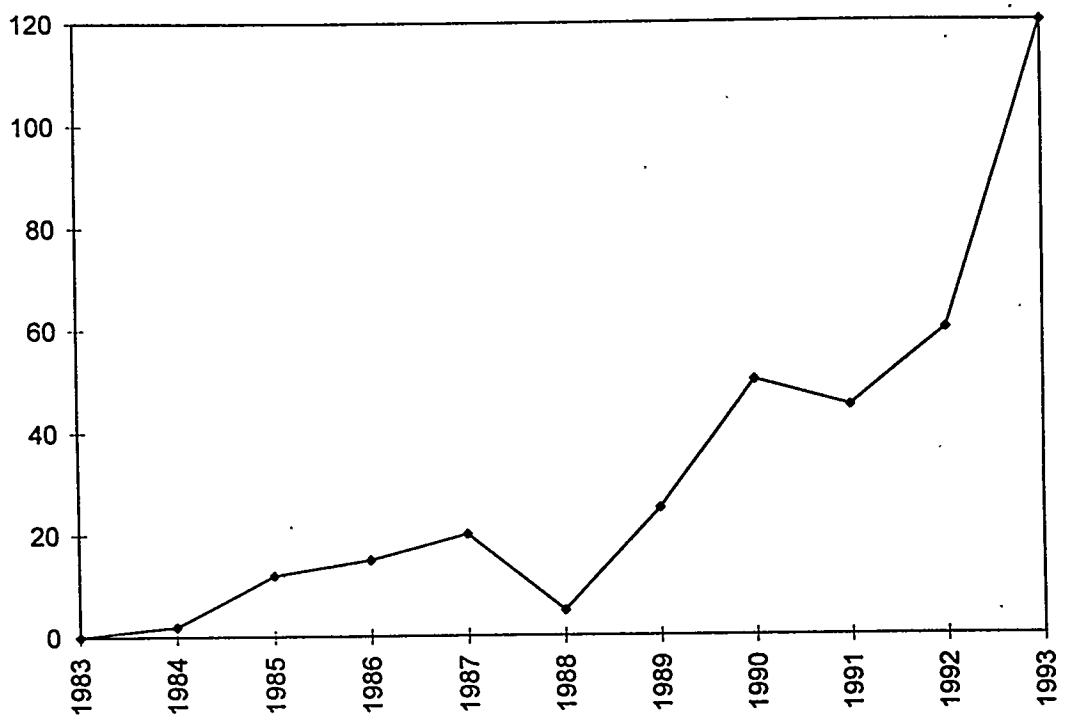


FIGURE 4.17 Number of Discoveries of Radioactive Materials in Recycled Metal Worldwide (Source: Lubenau and Yusko 1995)

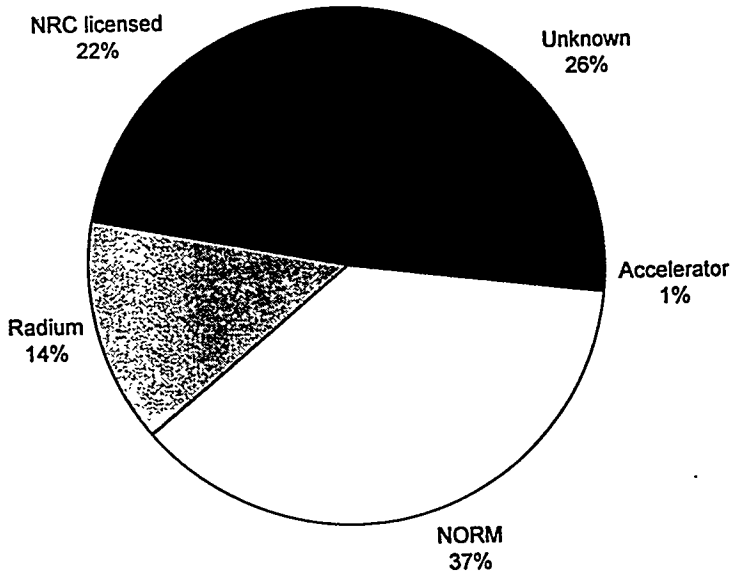


FIGURE 4.18 Relative Frequency of Radioactive Material Types Found in Recycled Metal (NORM = naturally occurring radioactive material [unspecified nuclides]) (Source: Lubenau and Yusko 1995)

To prevent contamination of storage yards and process equipment, current industry practice is to be very vigilant and to reject any shipments that have even the slightest possibility of containing radioactive scrap. However, radioactive materials still continue to slip through.

The Institute of Scrap Recycling Industries (1993) places radioactivity in scrap in three categories: inherently radioactive scrap, scrap bearing sealed radioactive material, and scrap contaminated with radioactive material. Materials in the first category usually have been exposed to intense radiation fields, such as those found in particle accelerators or nuclear reactors. Nuclear facilities are highly regulated and staffed with knowledgeable personnel, however, so it is unlikely that radioactive materials from these sources will inadvertently contaminate the scrap metal supply. Co-60 is a radioactive material that is frequently used to indicate deterioration of refractory brick in furnaces. Sometimes sufficient quantities of this material can melt and leach into a batch of metal to contaminate it. These occurrences are rare, and when they happen, the degree of contamination is usually minor. In other instances, radioactive materials are alloyed with other metals to improve performance characteristics. For example, magnesium-thorium alloys are commonly used in aircraft engines.

Inclusion of sealed radioactive sources with scrap has occurred fairly frequently. Common sources include medical therapy or industrial radiography devices, plated sources, level gauges, and other measuring devices. Sealed sources are usually found in construction and demolition debris, especially from industrial facilities. Gamma-emitting nuclides, such as Cs-137, Co-60, and Am-241 are most common, both in sheer numbers and in quantity of radioactive material (La Mastra 1989). These sources are also reasonably easy to detect with widely available technology. Large activity sources (in excess of 3.7×10^{12} Bq), usually contained in medical therapy or industrial radiography devices, pose potentially severe consequences if melted. It is estimated that there are probably fewer than 20,000 such devices in use nationwide in the U.S.A. (LaMastra 1989).

Scrap contaminated with radioactive material (the last category) occurs frequently in the mineral extraction industries. As a consequence of mineral extraction processes, scale can form inside piping and equipment. This scale may contain abnormally high concentrations of naturally occurring radioactive material (NORM), usually Ra-226. The NORM content in pipe scale from oil and gas drilling can vary from undetectable to up to 1,500 Bq/g (USEPA 1993). Other reports indicate that scale can exceed 3,700 Bq/g, a level of radioactivity that is about 100,000 times typical soil levels and that approaches levels found in uranium mines (Raloff 1991).

4.3.2 Radiation Detection Systems

In recent years, detection technology has improved significantly while costs have fallen, so some scrap yards have able to install fairly sophisticated radiation detection systems. The number of installed systems and the percentage of scrap metal being screened is not known, but both of these figures are probably rising. Some mills now insist as part of

the terms of purchase contracts that their scrap feedstocks be monitored for radioactivity. This stipulation make sense in light of recent cleanup costs at facilities inadvertently contaminated. Decontamination costs have averaged around $\$1 \times 10^6$ (U.S. dollars), and at one facility the cost of decontamination reached almost $\$4 \times 10^6$.

Many types of radiation detection equipment are available, but essentially three types have been found practical for monitoring scrap metal: ionization meters, event counters, and scintillation detectors (Yusko 1991). Ionization meters measure photons and beta particles (and some energetic alpha particles). The system becomes sensitive to ambient temperature and pressure changes. Ionization meters can provide a measure of the exposure or exposure rate from the source. Event detectors are the most commonly available meters, such as Geiger-Mueller tubes. These detectors also measure photons and particles, but the photons and particles must have higher energy to penetrate the sensitive volume of the detection chamber. Event counters provide a count or a count rate, but not the actual exposure (or dose) as is provided by ionization meters. Scintillation detectors absorb energy and convert it to an electric signal. These detectors can be very sensitive, but like ionization meters, are sensitive to environmental effects. When coupled with microprocessors, these detectors can be used to determine which radionuclide is present, although this degree of sophistication is unnecessary for monitoring scrap.

Detectors can be hand held or stationary. Hand-held detectors tend to be less sensitive, but they can be placed closer to the scrap to facilitate detection. Other advantages are that hand-held detectors can be taken to all parts of the yard, and they are usually less costly than stationary monitors. Stationary detectors tend to be much more sensitive and much more expensive than hand-held units. By strategically placing detectors near gates, however, nearly all scrap and waste entering and leaving a yard can be monitored.

Several factors influence the effectiveness of detection systems. Larger sources or those with more energetic radiation are easier to detect. However, the radiation may be shielded, either intentionally (as a sealed source) or inadvertently by scrap. Higher energy radiation is more difficult to shield, but even moderately high energy radiation can be shielded by several feet of steel scrap. Thick, dense material can more effectively shield a radiation source than thin and loosely packed material. Thus, a radioactive source is more likely to be missed in a shipment of steel plate than in aluminum scrap. Furthermore, increasing the distance from the source decreases the probability that it will be detected. To be effective, detectors should be placed as close to the scrap to be monitored as is practical. The effectiveness of detection systems may be enhanced by shielding the detector. In a field test, an unshielded 2 x 2 inch sodium iodide crystal detector had a background reading of around 1,500 counts per minute (cpm). With the alarm point set at two times background level, a minimal scrap covering would effectively prevent detection of a shielded source (La Mastra 1989). When the detector was shielded, the background count dropped to 70 cpm, and a typical gauge could be detected under about 0.3 m of steel scrap.

Another way to increase detection success is to check both incoming and outgoing scrap and waste products. A source that enters the processing yard undetected may be

exposed during processing by shifting the material and/or breaching a sealed source housing. These sources can be detected when the scrap leaves the yard. In addition, a significant number of detections at mills have occurred when monitors detected radiation in smelting wastes (slags and flue dust) as the waste was leaving the plant.

4.3.3 Current Practice

As noted above, an increasing number of scrap processing yards are being equipped with radiation detection systems, but it is not known how many yards have these systems or what percentage of scrap is monitored. One obstacle to adding more detection systems is the cost. The scrap business is extremely competitive, and many processors do not feel the additional cost is justified. Mills are generally seen as having greater financial resources to invest in monitors (and the consequences of contamination are more severe for mills). Some mills, however, now stipulate that their scrap feedstocks be monitored for radioactivity as a condition for taking delivery of the scrap.

The responses of processing yards and mills vary when radioactive scrap is detected. Some mills simply reject the entire shipment outright. Others shunt the suspect railcars or trucks aside to a special holding area and call in experts to assess the degree of radioactivity. Most sources that are identified are disposed of at low-level radioactive waste sites.

4.4 MARKET IMPACT OF RECYCLING RADIOACTIVE SCRAP METAL

As a consequence of dismantling nuclear facilities, large quantities of metal will become available for recycle. One concern is that the quantities of metal coming into the market will depress prices. For most of the metals reviewed in this study, however, impacts are expected to be minimal because the metal quantities are small relative to the size of the market. This section provides some measures of possible impacts and some perspective on the scrap market today.

Table 4.11 presents the projected average annual international RSM releases from nuclear power plants over the period 2010 to 2043. These estimates are added to the quantities of RSM from enrichment facilities. The resulting sum is doubled to account for RSM from weapons plants and other sources as well, producing the annual scrap flow estimates that follow. (See Section 3 for details of the basis for these estimates.) Iron and steel scrap together, at 5×10^5 t/yr, dominates the other metals and will provide by far the greatest quantity of scrap. Copper is second, at 1×10^5 t/yr, and stainless steel is third, at 4×10^4 t/yr.

Increasing the supply of scrap by recycling RSM is expected to create downward pressure on scrap prices, assuming the quantity of scrap metal demanded remains constant. But demand rarely remains constant, and the global economy has shown increasing volatility in recent years. In addition, other market forces can overwhelm this downward price pressure, either positively or negatively, especially if the quantity of new scrap metal coming on the market is a small fraction of the existing market flows. For example, increased

TABLE 4.11 Projected Average Annual Releases of Suspect and Surface-Contaminated — Removable Categories of Radioactive Scrap Metal from Power Plants Worldwide, 2010-2043

Region	Releases (t)				
	Aluminum	Copper	Lead	Iron and Steel	Stainless Steel
North America	400	20,600	100	58,400	300
Europe	400	23,800	100	5,900	700
Former Soviet Union	200	10,000	–[a]	53,500	5,200
Asia	200	10,300	–	8,300	1,900
Rest of World	–	1,200	–	4,100	400
Total[b]	1,200	65,900	300	29,800	17,500

[a] – denotes less than 100 t.

[b] Totals may not add due to rounding.

demand due to an improving global economy or increased secondary refining capacity could provide much greater upward price pressure. A worsening global economic climate would probably affect scrap prices more than would a small increase in supply. Another point to consider is that even if the increase in scrap supply leads to lower scrap metal prices, this situation will likely have a beneficial effect for scrap metal consumers.

Three measures were used to assess the potential impacts of recycling RSM. The first measure was to evaluate the ratio of the average quantity of RSM available from power plant decommissioning annually to the 1989 international scrap metal imports. This measure compares the quantity of metal the region was required to import with the potential RSM supply from power plants, because, to some extent, imports will be competing with this new source of metal. If the potential RSM is a small fraction of imports, then minimal impacts can be expected. On the other hand, the measure may be misleading for producing/exporting regions. These ratios, presented in Table 4.12, were computed for aluminum, copper, lead, and iron and steel for five regions of the world. The largest proportion of RSM to imports is for copper, averaging 4% for the world, but making up over 30% of the former Soviet Union copper imports. Such a large percentage for the former Soviet Union reflects a relatively small (2.5%) import volume compared with total domestic consumption (vs. 7.4% for North America or 24.9% for Europe). The proportions for other metals, however, amount to much less than 1% and, therefore, minimal impacts are expected from RSM supply.

One problem with the measure used above, as already explained, is that it may be skewed for exporting regions (leading to small imports and large ratios). A second measure developed was the ratio of the average quantity of RSM expected to be recycled each year to

TABLE 4.12 Projected Average Annual Radioactive Scrap Metal Flows for the Period 2010-2043 as Percentages of 1989 International Scrap Metal Imports

Region	Aluminum (%)	Copper (%)	Lead (%)	Iron and Steel (%)
North America	0.14	9.62	0.26	2.29
Europe	0.04	2.33	0.07	0.46
Former Soviet Union	–[a]	30.59	0.28	4.63
Asia	0.03	2.08	0.03	0.14
Rest of World	0.76	2.33	0.43	1.45
Total	0.06	3.73	0.08	0.56

[a] No imports reported for 1989.

the quantity of commodity metal consumption in 1989. Ideally, the best data to use for the denominator would be the quantity of secondary metal consumed, but this value was available only for iron and steel scrap. Ratios for the other metals include primary metal consumption in the denominator, and thus may underestimate the impacts of RSM recycling. These ratios are presented in Table 4.13 and display the same overall pattern as in Table 4.12, except that the measures are an order of magnitude smaller. Thus, the copper ratio is less than 1%, and the other ratios are negligible. Furthermore, each region has similar measures, and none varies much from the average. From this measure, one might conclude that because the projected quantity of recycled RSM is small relative to current metal consumption, the impacts from recycling RSM are likely to be insignificant.

A third measure compares the quantity of projected RSM to be recycled to the annual volatility of scrap consumption. Annual scrap consumption data were available only for iron and steel. Figure 4.19 illustrates the scrap iron and steel consumption for the five-year

TABLE 4.13 Projected Average Annual Radioactive Scrap Metal Flows for the Period 2010-2043 as Percentages of 1989 International Commodity Metal Consumption

Region	Aluminum (%)	Copper (%)	Lead (%)	Iron and Steel (%)
North America	0.01	0.78	0.01	0.08
Europe	0.01	0.63	0.01	0.08
Former Soviet Union	0.01	0.85	0.00	0.05
Asia	0.00	0.25	0.00	0.03
Rest of World	0.00	0.23	0.00	0.02
Total	0.01	0.56	0.00	0.06

period from 1985 to 1989. A simple estimate of volatility was computed as the average absolute value of the year-to-year change in iron and steel scrap consumption over the period. The ratios computed from this quantity are shown in Table 4.14. This measure indicates that the quantity of iron and steel scrap available to be recycled each year averages a little more than 2% of the year-to-year volatility from 1985 to 1989. Thus, this measure also suggests that the market impact of recycling iron and steel will be minimal.

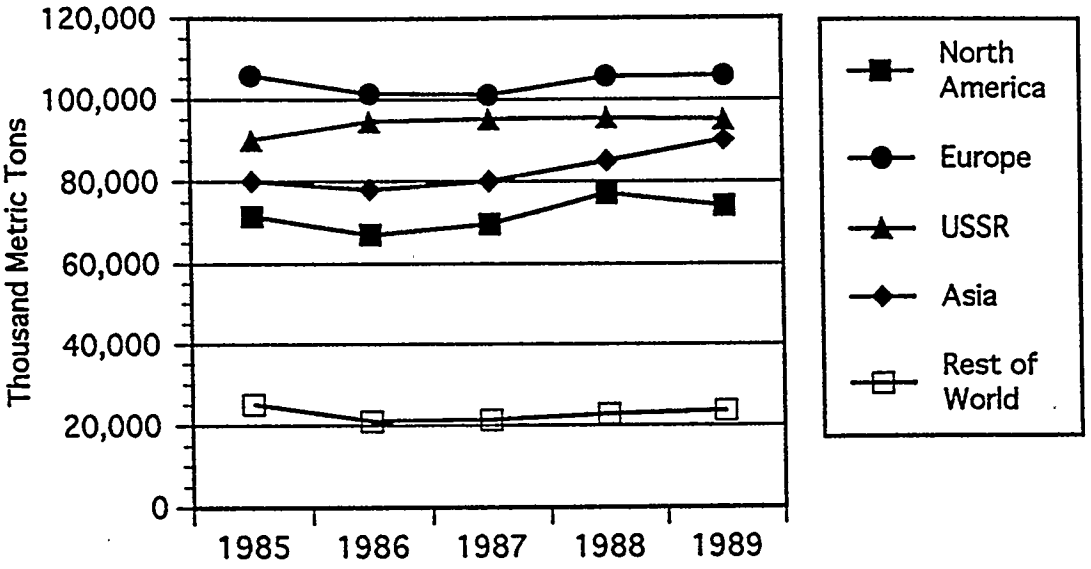


FIGURE 4.19 International Scrap Iron and Steel Consumption, 1985-1989 (Source: United Nations 1991)

TABLE 4.14 Comparison of Projected Annual Average Quantity of Radioactive Scrap Metal Iron and Steel Available, 2010-2043, with Scrap Iron and Steel Consumption Volatility, 1985-1989

Region	Volatility[a] (10^3 t)	Ratio[b] (%)
North America	4,447	1.27
Europe	2,383	3.48
Former Soviet Union	1,425	3.48
Asia	3,500	0.69
Rest of World	1,651	0.23
Total	9,275	2.34

[a] The average absolute value of year-to-year changes in consumption over the time period.

[b] Ratio of average annual quantity of RSM iron and steel available over the period 2010-2043 to 1985-1989 volatility.

In conclusion, several measures were developed to assess the market impact of recycling the projected quantities of RSM. Copper may experience some downward price pressure. This situation would cause some difficulty for the scrap processors specializing in copper, but it should benefit downstream consumers. Other metal markets will probably not experience measurable impacts.

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5 IMPACTS OF RADIOACTIVE SCRAP METAL RECYCLING

This section presents an evaluation of potential health and environmental impacts of radioactive scrap metal (RSM) recycling. Section 5.1 provides an overview of the tiered release concept and of the major process activities involved in RSM recycling. The main types of health risks and environmental impacts that are likely to be associated with each process activity are discussed, and iron and steel are used as an example. Radiological risks to human health are assessed in Section 5.2, and nonradiological risks are assessed in Section 5.3. The discussion of radiological risks is more detailed because of the need to explore issues related to potential development of international standards for recycling. Section 5.4 discusses environmental impacts in terms of the nature and relative magnitude of effects on environmental quality and resources. The study scope did not include cost estimates for recycling.

5.1 OVERVIEW OF THE RECYCLE PROCESS

To date, relatively small quantities of RSM from various facilities have been recycled for public use, whereas thousands of tons have been recycled within the nuclear industry (Menon and Teunckens 1994; Hertzler et al. 1993). The magnitude of the potentially available supply and the very low level of radioactivity in a major portion of it (see discussion in Section 3) warrant consideration of a broad range of end uses for this material. To that end, a tiered system of release criteria for a wide range of product end uses is evaluated.

A tiered -release approach has the advantage of matching RSM supply with product demand while controlling public health risks and environmental impacts to meet international guidelines. Health risks are controlled by tailoring release levels to both the radiological characteristics of the scrap and its potential end uses. Figure 5.1 provides an overview of the conceptual process evaluated for RSM recycling. Four major types of material release are considered: unrestricted reuse of items in their original form, unrestricted recycle of melt-decontaminated metal into new products, prescribed initial use of metal products produced in a controlled environment, and controlled recycling within the nuclear industry. The tier definitions are summarized in Table 5.1, which also indicates the scope of the health risk assessment conducted for each tier.

Unrestricted reuse (Tier A) is evaluated for equipment or metal components or surfaces of buildings (e.g., office furniture, tools, or structural steel). The contamination may be either surface or volumetric and the metal is assumed to be surface decontaminated prior to certification for release. It is recognized that certification of volumetrically contaminated objects may present practical difficulties, however this assessment focusses on exposure risks, not limitations in activity detection capabilities. Health risks are evaluated for decontamination prior to release, transportation, public use, and disposal in a landfill. Scenarios assuming that large masses of metal released for reuse might be either recycled in a commercial smelter or disposed of in a municipal landfill were evaluated to assure that such an eventuality would not pose an unacceptable risk. In actuality, recycling or disposal of metal released for unrestricted reuse is likely to occur in circumstances that produce

TABLE 5.1 Tier Structure, End-Use Options, and Scope of Analysis for Radioactive Scrap Metal Recycle Alternatives

Recycle/Reuse Alternatives	Decontamination Method	Nature of Contamination at Release	Release Form	End-Use Options	Health Risks Evaluated
Unrestricted reuse (Tier A)	Surface decontamination	Surface/volume	Equipment, Buildings	Reuse in present form with eventual recycle by commercial smelter into products	Radiation: Product use, landfill disposal, transportation Chemical: Decontamination worker, public from decontamination Accidents: Transportation
Unrestricted recycle (Tier B)	Surface decontamination and controlled melting	Volume	Ingot	Commercial remelt and/or commercial milling into products	Radiation: Smelter worker, public from smelter emissions, distribution worker, product use, public from landfill disposal, transportation Chemical: Decontamination worker, public from decontamination, public from smelter emissions Accidents: Smelter worker, transportation
Prescribed initial recycle (Tier C)	Surface decontamination and controlled melting and milling	Volume	Final product	Specified public uses	Radiation: Product use, public from landfill disposal, transportation Chemical: Decontamination worker, public from decontamination, public from smelter emissions Accidents: Smelter worker, transportation
Controlled use (Tier D)	Surface decontamination/ smelting	Volume	No release	Reuse/recycle for nuclear industry use	Not evaluated

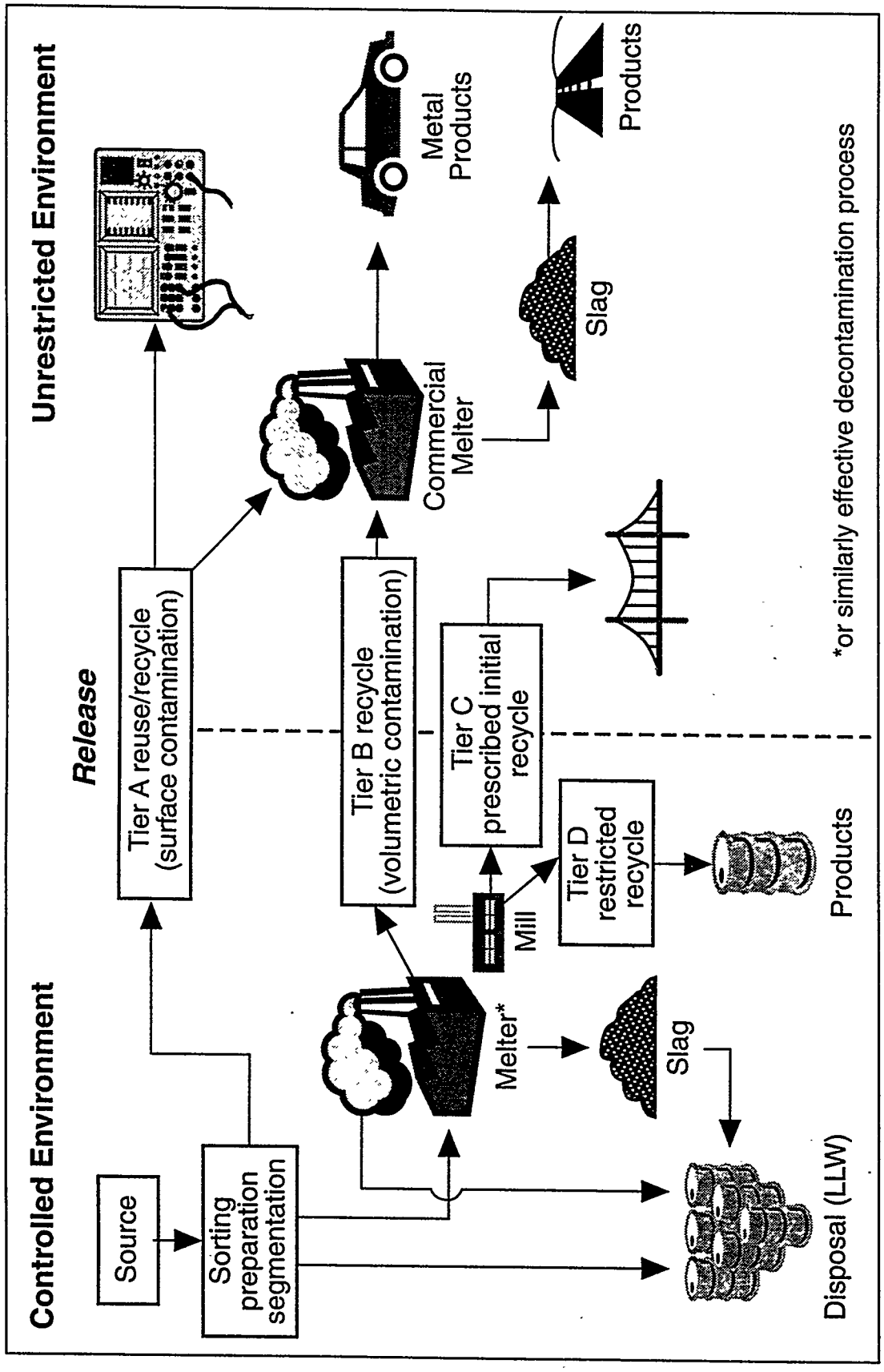


FIGURE 5.1 Process for Assessment and Release of Radioactive Scrap Metal

extreme dilution of the activity. The unrestricted recycle process (Tier B) pertains to scrap with fixed-surface or volumetric activity that would be decontaminated and then melted in a controlled (licensed) facility. Melting in a controlled facility prior to release serves as a decontamination measure for some radionuclides and also has a very important function in facilitating measurement of the activity in the metal. Ingots would then be released for recycling. The primary expectation is that these would be remelted at a commercial smelter where they are likely to be diluted with other scrap, but the possibility that they might be milled without dilution is also evaluated. Health risks for Tier B recycling are evaluated for decontamination of the metal prior to and in the controlled melt, ingot processing in a commercial smelter, smelter emissions, product distribution, transportation, and landfill disposal. Radiation exposure scenarios are evaluated for a wide range of metal products in unrestricted uses. Slag from the commercial melting is assumed to be used in paving highways or parking lots.

Tier C release requires restricted distribution of finished metal products from a controlled melting and milling facility to prescribed initial uses that involve minimal public exposure. In the future, when the metal is again recycled (30 years assumed), it would be treated as common scrap. The main advantage of Tier C is the ability to recycle metals that are contaminated with relatively short-lived radionuclides while controlling health risks. For Tier C, external exposure is the only pathway potentially affecting health risk for the public. Omitting the commercial smelting and milling operations, the evaluation covered the same aspects as for unrestricted recycle (Tier B). Similarly to the unrestricted reuse case, any eventual recycling or disposal is likely to result in great dilution of any activity remaining in the metal.

Usable metal with activity that it is infeasible or impractical to reduce to Tier C levels would be recycled for use in environments with radiation controls (Tier D). The controlled use alternative is not discussed in this report. Related issues are addressed in programs such as the U.S. Department of Energy's Recycle 2000 initiative (Warren 1995). If even controlled recycling were judged technically or economically infeasible, scrap is assumed to be disposed of as low-level waste (LLW).

5.2 RADIOLOGICAL HEALTH EFFECTS

For the RSM recycling, radiological health risks were estimated for product end-use scenarios, as well as for emissions from commercial smelting of RSM, for product transportation, and for unrestricted landfill disposal of discarded RSM products. Detailed assessments of potential health risks were conducted for commercial metal workers and the general public. Radiological risks to health from activities of radiation workers prior to RSM release — such as metal sorting, decontamination, and packaging — were not evaluated in detail because these activities would take place in an environment where exposures would occur under regulatory limits. Such exposures might be required for either recycling or disposal of RSM. Disposal of RSM residuals at a LLW site would also be carried out by

radiation workers, and exposures would be controlled by existing regulatory requirements. The risk estimates for disposal of RSM as LLW are based on regulatory limits and previous studies.

5.2.1 Assessment Methodology

Potential radiological impacts from the RSM alternatives were assessed in terms of the total effective dose equivalent (10 CFR 20 [USNRC 1990]), which is the sum of the effective dose equivalent from external exposures and the committed effective dose equivalent from internal exposures. Health impacts, expressed in terms of cancer fatalities, were obtained by multiplying the total effective dose equivalent by the health effects conversion factor of 5×10^{-2} fatal cancers per sievert (Sv) (International Commission on Radiological Protection [ICRP] 1991). Total cancer incidence is two to three times the cancer fatality rate.

Radiological risks from metal recycle/reuse have been analyzed by various U.S. and international organizations (O'Donnell et al. 1978; U.S. Nuclear Regulatory Commission [USNRC] 1980; Commission of the European Communities [CEC] 1988, 1995; International Atomic Energy Agency [IAEA] 1992; S. Cohen & Associates, Inc. 1995). This independent analysis was conducted to:

- Develop and evaluate an expanded set of scenarios — including smelting emissions, landfill disposal, and transportation — that is appropriate for the tiered release concept proposed in this study,
- Expand the nuclide categories considered to include volatile elements and radon parents (which may have been previously regulated, e.g., radium),
- Incorporate recently developed methodology and available information, and
- Emphasize a realistic approach to development of release standards.

The objective of this study is to (1) calculate baseline doses for the recycling alternatives and options by using conservative parameters; (2) perform a sensitivity analysis for key parameters to determine uncertainty levels and the degree to which they have been handled conservatively; and (3) advance the concepts of previous studies by identifying potentially appropriate release limit ranges on the basis of additional information regarding important parameters and using dose criteria that, in themselves, are protective of human health. Findings of the sensitivity analysis are discussed in Appendix C.

5.2.1.1 Technical Approach

Radiological impacts have been analyzed with the RESRAD-BUILD methodology developed at Argonne National Laboratory (Yu et al. 1994; methodology described in

Appendix C). The framework of exposure scenarios and assumptions was taken from the IAEA Safety Series No. 111 (IAEA 1992). The IAEA methodology is similar to the USNRC approach documented in NUREG/CR-5512 (USNRC 1992) but with more detailed analytical features. This approach is designed to serve as a "screening model," whereas the RESRAD-BUILD assesses exposures in more detailed environmental settings. Inclusion of features such as room size and ventilation rate allow RESRAD-BUILD to investigate effects of parameters that are unavailable in previous studies, such as impacts from radon gases and the progeny radionuclides.

Three pathways were analyzed: inhalation of particulates and radon progeny, ingestion, and external gamma irradiation. Exposure estimates for the inhalation and ingestion pathways were calculated with the default parameters suggested by NUREG/CR-5512 and IAEA Safety Series No. 111. The internal dose conversion factors are based on ICRP Publication 30 (ICRP 1979), and the external dose conversion factors are derived from U.S. Environmental Protection Agency (USEPA) Federal Guidance Report No. 12 (USEPA 1993c). Impacts to the public from any radioactive emissions during the commercial melting process were also assessed. This analysis employed the CAP-88 code (USEPA 1992), assuming a generic urban environmental setting. For unrestricted disposal, health risks of RSM at a public landfill were assessed with the RESRAD code (Yu et al. 1993a).

Radionuclides can be categorized on the basis of several different considerations, such as the type and energy of radiation emitted (i.e., alpha, beta, or gamma) or the significant pathway (e.g., inhalation, ingestion, or external exposure). In general, doses are dominated by the inhalation pathway for alpha emitters, the ingestion pathway for beta emitters, and the external exposure pathway for gamma emitters. Gamma emitters are typically products of neutron activation associated with nuclear power plant operation; beta emitters are mostly fission products typically associated with spent nuclear fuel reprocessing; and alpha emitters are generally associated with nuclear fuel processing and enrichment operations. In addition, other nuclides — such as radon parent nuclides, tritium, and volatile elements (e.g., iodine) — exhibit environmental behavior that presents special problems regarding health impacts to humans, and these nuclides are included in this analysis of metal recycling risks.

On the basis of these considerations, five preliminary categories of nuclides were identified as providing an effective basis for defining release levels. These categories include alpha emitters, beta emitters, gamma emitters, volatile nuclides, and radon parents. Nuclides with constraining doses were selected for presentation from a broad preliminary assessment. These nuclides include Ac-227, Am-241, Pu-239, and U-238 for alpha emitters; Sr-90 and Tc-99 for beta emitters; Co-60, Cs-137, and Zn-65 for gamma emitters; H-3 and I-129 for volatile nuclides; and Ra-224, Ra-226, Th-230, and Th-232 for radon parents. The latter two categories of nuclides were analyzed only for reuse of surface contaminated objects under the product end use and unrestricted disposal scenarios. Exposure pathways for commercial smelter workers or public end-use scenarios have not been identified for either volatile nuclides or radon under the RSM recycle options because volatile nuclides would be

removed in the controlled melt and because the radon parents are incorporated in slag or metal where the radon is immobilized.

5.2.1.2 Derivation of Release Levels

In view of the international perspective of this analysis, a dose criteria of 10 μSv/yr per practice to an average member of the "critical group," as recommended by the IAEA (1988), was used for illustrative purposes. The "critical group" is defined as a group of individuals who are "representative of individuals receiving the highest levels of dose from a particular practice, and is defined so that it is reasonably homogeneous with respect to factors that affect the dose received" (IAEA 1988). Collective dose commitments to the general public over the useful life of the metal products are compared to the IAEA-recommended level of 1 person-Sv/yr of a practice. Although the term "practice" has not been clearly defined, one suggested interpretation is the site producing materials for recycle or reuse (IAEA 1992). For this analysis, a "practice" is interpreted as a single commercial smelter/mill that accepts 50,000 t/yr of RSM ingots and produces consumer products. Details of the derivation of release levels in accordance with these principles are described in Appendix C.

5.2.2 Dose Estimates

Dose estimates were calculated for each of the major population groups and exposure situations that were identified.. Doses are presented for commercial smelter workers, the public exposed to items released for reuse or products made with recycled RSM, the public exposed to smelter emissions, workers and the public exposed during RSM transportation, and the public exposed through RSM disposal in a municipal landfill or smelting residuals disposed in a LLW repository.

Individual dose estimates were calculated for each recycling tier and associated scenarios. Two basic parameters that play a key role in all RSM recycle (Tier B and C) scenarios for both worker and public doses are the RSM dilution rate and radionuclide partitioning factors (see Appendix C for a detailed discussion). In some previous studies, the baseline dose estimates have not specifically accounted for dilution of the RSM with uncontaminated metal or partitioning of the activity among ingots, slag and offgas/dust as a result of the melt process (e.g., O'Donnell et al. 1978; CEC 1988; IAEA 1992). Incorporating realistic values for these parameters substantially reduces conservatism in dose estimates. A parameter sensitivity analysis and definition of analytical cases is presented in Appendix C. The modified-conservative case, which is shown in the following tables, incorporates the two most sensitive parameters. The RSM dilution factor is assumed to be 1:10, and nuclide partitioning factors from the literature are applied. The sensitivity of individual dose estimates to various parameters is discussed in Appendix C.

Population dose is estimated by summing all committed doses over the duration of product life for exposed population groups, based on the distribution of metal in end products.

Because the population dose accounts for the total exposure resulting from a year of RSM recycling operations, it is highly dependent on the annual throughput. The relation of throughput to unrestricted reuse applications is highly uncertain, so population dose was not calculated for Tier A. Population doses based on an RSM throughput of 50,000 t/yr have been estimated for both Tiers B and C, with appropriate nuclide partitioning factors applied. The dilution factor was not considered because the total amount of activity available for population exposure is unaffected by dilution (i.e., dilution does not alter the amount of activity released). For workers, committed doses from all work steps associated with an unrestricted recycle practice are summed; for the general public, committed doses from all RSM end uses under either unrestricted recycle or prescribed initial use are considered separately.

5.2.2.1 Doses to Industrial Workers from Recycling

In each of the unrestricted recycle activities, commercial metal workers would receive exposures from the RSM. Worker scenarios for each step in the recycle process, which are presented in detail in Appendix C, are adapted from Safety Series No. 111 (IAEA 1992). Pathways for workers include inhalation, ingestion, and external exposures from metal preparation, smelting, and processing activities. Annual baseline doses for workers were estimated on the basis of 2,000 hours of exposure and were scaled for throughput levels of 10,000 and 50,000 t of RSM. Doses from metal processing under the unrestricted reuse and prescribed-first-use scenarios and for controlled recycle are limited to nuclear facility workers. For these potential end uses of RSM, plant practices and controls on radiological exposure would limit doses to levels consistent with regulatory requirements, so dose estimates were not developed.

Table 5.2 lists constraining individual worker doses and derived activity levels for release of ingots to a commercial smelter and to a commercial mill. The derived activity levels, which are discussed further in Section 5.2.3, are for the metal at the point of release from the originating facility, decontamination facility, or controlled melter/mill. The ranges of levels for representative nuclides show the effect of throughput assumptions of 10,000 and 50,000 t annually and potential effects of protective measures, such as respiratory protection or remote handling, for workers. For release to a smelter the constraining doses are for the slag worker and small object caster scenarios. The sheet and coil worker scenarios are constraining for release to a mill, which only involves rolling and fabrication of the metal.

Worker population doses for unrestricted recycle are presented in Table 5.3. In the dose calculations, the number of full-time workers was scaled for a 50,000 t/yr throughput. Dose estimates for remelting the ingots are dominated by doses to slag workers and small object casters, which constitute about 70% of the dose for alpha emitters. For gamma emitters, external doses to coil workers and warehouse workers are significant (more than 50% of total dose). The analysis of population dose for remelting of ingots bounds the case for of direct milling and fabrication of the metal without dilution. In the direct milling case, inhalation dose would be almost entirely avoided and exposure of workers in melt and slag operations would be avoided.

TABLE 5.2 Summary of Constraining Individual Worker Doses and Derived Activity Levels for Unrestricted Recycle Worker Scenarios with 10,000 and 50,000 t Throughput

Representative Nuclide	Constraining Scenario Individual Dose[a] (μSv/yr)	Derived Activity Level (Bq/g)		
		10,000 t[b]	50,000 t[c]	50,000 t with Protection[d]
Unrestricted release of ingots to commercial melting (Tier B)[e]				
Ac-227	4.9×10^{1}	1.0×10^{0}	2.1×10^{-1}	2.1×10^{1}
Am-241	2.1×10^{0}	2.4×10^{1}	4.7×10^{0}	4.7×10^{2}
Pu-239	1.5×10^{0}	3.4×10^{1}	6.9×10^{0}	6.9×10^{2}
U-238	2.2×10^{0}	2.3×10^{1}	4.5×10^{0}	4.5×10^{2}
Sr-90	4.4×10^{-1}	1.1×10^{2}	2.3×10^{1}	2.3×10^{3}
Tc-99	1.1×10^{-2}	4.8×10^{3}	9.5×10^{2}	9.5×10^{4}
Co-60	1.5×10^{1}	3.4×10^{0}	6.9×10^{-1}	-[f]
Cs-137	4.5×10^{1}	1.1×10^{0}	2.2×10^{-1}	-[f]
Zn-65	3.4×10^{-1}	1.5×10^{2}	2.9×10^{1}	-[f]
Unrestricted release of ingots to commercial milling (Tier B)[g]				
Ac-227	8.1×10^{0}	6.2×10^{0}	1.2×10^{0}	-[f]
Am-241	5.3×10^{-1}	9.4×10^{1}	1.9×10^{1}	-[f]
Pu-239	1.3×10^{-3}	3.8×10^{4}	7.5×10^{3}	-[f]
U-238	5.5×10^{-1}	9.1×10^{1}	1.8×10^{1}	-[f]
Sr-90	9.4×10^{-2}	5.3×10^{2}	1.1×10^{2}	-[f]
Tc-99	7.0×10^{-4}	7.2×10^{4}	1.4×10^{4}	-[f]
Co-60	6.0×10^{1}	8.4×10^{-1}	1.7×10^{-1}	-[f]
Cs-137	1.3×10^{1}	3.8×10^{0}	2.2×10^{-1}	-[f]
Zn-65	9.0×10^{0}	5.5×10^{0}	1.1×10^{0}	-[f]

[a] Doses are based on an RSM activity concentration of 1 Bq/g at the point of release. For the commercial melting case, a dilution rate of 1:10 and nuclide partitioning factors are applied.

[b] Activity that results in an annual dose of less than 10 μSv with 10,000 t RSM throughput annually.

[c] Activity that results in an annual dose of less than 10 μSv with 50,000 t RSM throughput annually.

[d] Respiratory protection factor of 0.01 applied to dose.

[e] All values are based on the slag worker scenario, except those for Co-60, which are for the small object caster scenario.

[f] Using remote control, all pathways could be controlled to the prescribed level.

[g] Values are based on the coil and sheet worker scenarios.

TABLE 5.3 Worker Population Doses for Unrestricted Recycle Based on Annual Smelter Throughputs of 10,000 t and 50,000 t of Radioactive Scrap Metal

Representative Nuclide	Population Dose (person-Sv/yr)[a] 10,000 t Radioactive Scrap Metal	50,000 t Radioactive Scrap Metal
Ac-227	1.2×10^{-3}	6.1×10^{-3}
Am-241	6.1×10^{-5}	3.1×10^{-4}
Pu-239	5.6×10^{-5}	2.8×10^{-4}
U-238	4.3×10^{-5}	2.1×10^{-4}
Sr-90	1.1×10^{-5}	5.4×10^{-5}
Tc-99	4.4×10^{-7}	2.2×10^{-6}
Co-60	5.1×10^{-3}	2.5×10^{-2}
Cs-137	6.9×10^{-4}	3.5×10^{-3}
Zn-65	7.1×10^{-5}	3.5×10^{-4}

[a] Doses are based on a RSM activity concentration of 1 Bq/g and nuclide partitioning factors. The throughput is assumed to be undiluted.

5.2.2.2 Doses to the Public from Reuse/Recycling

Public Reuse — Tier A. Two scenarios were analyzed for unrestricted release of surface-contaminated objects for reuse. A standard, conservative building occupancy scenario (USNRC 1992) was analyzed for reuse of a building or as a bounding case for large equipment. Uniform contamination of the four walls of a 5 × 5 × 3 m room was assumed. A less conservative scenario was also developed for surface contamination of an area of 1 m^2, which was assumed to generically characterize small tools or equipment. (See Appendix C for scenario detail.) Doses from surface contamination could occur through inhalation (including radon and its progeny), ingestion and external pathways.

The modified-conservative case results shown in Table 5.4 assumed that the surface has been decontaminated to the extent that only 1% of the activity present can become airborne. Parent nuclides with decay chains that emit radon and its decay progeny are included in the evaluation. Nuclides having significant radon doses include Ra-224, Ra-226, Th-230 and Th-232.

TABLE 5.4 Constraining Individual Public Doses and Derived Activity Levels under Scenarios for Reusing Radioactive Scrap Metal Objects

Nuclide Category	Representative Nuclide	Surface-Contaminated Objects: Tools and Equipment[a] Individual Dose[c] (μSv/yr)	Surface-Contaminated Objects: Tools and Equipment[a] Derived Activity Level[d] (Bq/cm^2)	Surface-Contaminated Objects: Building Occupancy Individual Dose[c] (μSv/yr)	Surface-Contaminated Objects: Building Occupancy Derived Activity Level[d] (Bq/cm^2)	Volumetrically Contaminated Objects: Tools and Equipment[b] Individual Dose[e] (μSv/yr)	Volumetrically Contaminated Objects: Tools and Equipment[b] Derived Activity Level[d] (Bq/cm^2)
Alpha	Ac-227	8.5×10^{0}	1.2×10^{0}	4.0×10^{2}	2.5×10^{-2}	9.1×10^{0}	1.1×10^{0}
	Am-241	9.1×10^{-1}	1.1×10^{1}	4.2×10^{1}	2.4×10^{-1}	2.2×10^{-1}	4.6×10^{1}
	Pu-239	6.9×10^{-1}	1.5×10^{1}	4.0×10^{1}	2.5×10^{-1}	1.5×10^{-3}	6.9×10^{3}
	U-238	2.7×10^{-1}	3.7×10^{1}	7.7×10^{0}	1.3×10^{0}	6.2×10^{-1}	1.6×10^{1}
Beta	Sr-90	3.7×10^{-2}	2.7×10^{2}	9.1×10^{-1}	1.1×10^{1}	1.1×10^{-1}	9.4×10^{1}
	Tc-99	5.9×10^{-4}	1.7×10^{4}	9.9×10^{-3}	1.0×10^{3}	6.2×10^{-4}	1.6×10^{4}
Gamma	Co-60	9.3×10^{0}	1.1×10^{0}	3.4×10^{1}	3.0×10^{-1}	6.7×10^{1}	1.5×10^{-1}
	Cs-137	2.3×10^{0}	4.4×10^{0}	8.6×10^{0}	1.2×10^{0}	1.5×10^{1}	6.7×10^{-1}
	Zn-65	1.5×10^{0}	6.8×10^{0}	5.3×10^{0}	1.9×10^{0}	1.0×10^{1}	9.8×10^{-1}
Volatile nuclides	H-3	6.3×10^{-4}	1.6×10^{4}	3.8×10^{-2}	2.6×10^{2}	[f]	[f]
	I-129	1.7×10^{0}	5.9×10^{0}	1.0×10^{2}	1.0×10^{-1}	[f]	[f]
Radon[g]	Ra-224	6.8×10^{0}	1.5×10^{0}	4.1×10^{2}	2.4×10^{-2}	[f]	[f]
	Ra-226	2.7×10^{1}	3.7×10^{-1}	1.6×10^{3}	6.3×10^{-3}	[f]	[f]
	Th-232	6.2×10^{2}	1.6×10^{-2}	3.7×10^{4}	2.7×10^{-4}	[f]	[f]

[a] Area of surface contamination is 1 m^2 for generic assessment of tools and equipment.

[b] For volumetric contamination, the ingot caster scenario is used for generic assessment of tools and equipment.

[c] Doses are based on a radionuclide activity concentration of 1 Bq/cm^2 (after decontamination) and a surface transfer factor of 0.01.

[d] Activity concentration that results in an individual dose of 10 μSv/yr.

[e] Doses are based on a radionuclide activity concentration of 1 Bq/g.

[f] Not analyzed.

[g] Ra-224 and Ra-226 are parent nuclides of Rn-220 and Rn-222, respectively; Th-232 decays to Ra-224.

For unrestricted reuse of volume-contaminated tools, only external exposure is included in the dose calculation because all contamination is assumed to be immobile. The ingot caster scenario geometry based on Safety Series 111-P-1.1 (IAEA 1992) was used assuming no dilution or partitioning of nuclides. Table 5.4 presents individual doses and derived release levels for reuse of surface-contaminated tools and building areas, and for volumetrically contaminated tools.

Recycle to Consumer Products —Unrestricted Recycle or Prescribed Initial Use. Doses from the use of consumer products primarily result from external exposures to gamma radiation. However, for some nuclides, ingestion is the primary pathway under the frying pan scenario. The basic scenarios and assumptions follow Safety Series No. 111-P-1.1 (IAEA 1992). Products evaluated under unrestricted recycle scenarios include: automobile, frying pan, refrigerator, workplace walls, desk, and bed springs. Nuclide partitioning and dilution is assumed for commercial remelting of ingots. The commercial milling scenarios assume fabrication without remelting. The evaluation of commercial smelting also considers the use of slag in highway pavement. Modified-conservative-case doses for unrestricted recycle and prescribed first use are shown in Table 5.5. For products from unrestricted release to a smelter or a mill, the maximum individual doses are associated with the taxi driver scenario (external) and the frying pan scenario (ingestion).

External exposure is the only identifiable pathway to the public for the prescribed-initial-use scenarios. These scenarios were developed to represent the use of structural steel and reinforcing bars in bridges and public buildings. The constraining scenario for Tier C is the public building scenario.

Public population doses from product end-use scenarios (Tiers B and C) are also presented in Table 5.5. RSM throughput of 50,000 t was assumed to be distributed among end-use categories as follows: building materials 38%, automobiles 30%, frying pans 8%, home furniture 8%, office furniture 8% and appliances 8% (based on U.S. Bureau of Mines [1985]). From the metal mass of each end-use product and the RSM throughput, the number of products potentially distributed annually is estimated as a basis for calculating total public exposure. Population doses for unrestricted recycle (Tier B) are dominated by the building occupancy (20 to 40%) and frying pan (10 to 30%) scenarios. For prescribed initial uses, Tier C, the constraining population dose is from use of rebar in a public building. In both tiers, Co-60 population doses substantially exceed 1 person-Sv.

5.2.2.3 Doses to the Public from Smelter Emissions

Dose estimates for radioactive emissions during commercial smelting of recycled ingots are presented in Table 5.6 for the maximally exposed individual. The committed dose to the public was estimated on the basis of a 50,000-t/yr RSM throughput containing 1 Bq/g of each nuclide. Doses are predominantly from the inhalation pathway; exposures to residual activity after the first year and from other pathways are negligible. Partitioning factors

TABLE 5.5 Constraining Individual Public Doses and Derived Activity Levels under Scenarios for Unrestricted Recycling of Radioactive Scrap Metal

Representative Nuclide	Individual Dose[a] (μSv/yr)	Derived Activity Level[b] (Bq/g)	Population Dose[a,c] (person-Sv)
Consumer products from ingot recycle in a commercial smelter[d]			
Ac-227	2.4×10^{-1}	4.1×10^{1}	4.5×10^{0}
Am-241	5.8×10^{-2}	1.7×10^{2}	1.2×10^{0}
Pu-239	7.1×10^{-3}	1.4×10^{3}	5.9×10^{-1}
U-238	2.3×10^{-2}	4.4×10^{2}	3.0×10^{-1}
Sr-90	1.2×10^{-3}	8.6×10^{3}	3.4×10^{-2}
Tc-99	6.2×10^{-5}	1.6×10^{5}	9.5×10^{-4}
Co-60	8.3×10^{0}	1.2×10^{0}	6.2×10^{1}
Cs-137	2.2×10^{-3}	4.6×10^{3}	2.5×10^{-2}
Zn-65	1.4×10^{-2}	7.2×10^{2}	2.7×10^{-2}
Pavement using slag from ingot recycle in a commercial smelter[e]			
Ac-227	3.3×10^{-3}	3.0×10^{3}	1.5×10^{-1}
Am-241	7.9×10^{-5}	1.3×10^{5}	4.0×10^{-3}
Pu-239	5.2×10^{-7}	1.9×10^{7}	2.6×10^{-5}
U-238	2.3×10^{-4}	4.4×10^{4}	1.2×10^{-2}
Sr-90	3.5×10^{-5}	2.9×10^{5}	1.6×10^{-3}
Tc-99	2.3×10^{-8}	4.4×10^{8}	1.2×10^{-6}
Co-60	2.3×10^{-4}	4.4×10^{4}	6.9×10^{-3}
Cs-137	5.5×10^{-3}	1.8×10^{3}	2.5×10^{-1}
Zn-65	3.7×10^{-5}	2.7×10^{5}	2.9×10^{-4}
Consumer products from ingot recycle in a commercial mill[d]			
Ac-227	2.4×10^{1}	4.1×10^{-1}	2.7×10^{1}
Am-241	5.8×10^{0}	1.7×10^{0}	7.2×10^{0}
Pu-239	7.1×10^{-1}	1.4×10^{1}	1.2×10^{1}
U-238	2.3×10^{0}	4.4×10^{0}	2.9×10^{0}
Sr-90	1.2×10^{-1}	8.6×10^{1}	1.3×10^{-1}
Tc-99	6.2×10^{-3}	1.6×10^{3}	7.8×10^{-3}
Co-60	8.3×10^{1}	1.2×10^{-1}	6.2×10^{1}
Cs-137	2.2×10^{1}	4.6×10^{-1}	2.5×10^{1}
Zn-65	1.4×10^{1}	7.2×10^{-1}	2.7×10^{0}
Prescribed initial use after controlled melt and milling[f]			
Sr-90	3.4×10^{-2}	3.0×10^{2}	3.0×10^{-1}
Co-60	1.9×10^{1}	5.2×10^{-1}	6.3×10^{1}
Cs-137	3.2×10^{0}	3.1×10^{0}	2.9×10^{1}
Zn-65	2.9×10^{0}	3.4×10^{0}	1.9×10^{0}

Footnotes appear on next page.

TABLE 5.5 (Cont.)

[a] Doses are based on an RSM activity concentration of 1 Bq/g in the ingots and in prescribed-initial-use products. Modified-conservative case assumptions are applied to release to a commercial smelter, a dilution rate of 1:10, and nuclide partitioning factors.

[b] Activity concentration that results in an exposure of 10 μSv/yr.

[c] Doses are based on 50,000 t of RSM. Cumulative population dose over long-term use is included in the doses shown here.

[d] With one exception, the constraining scenario is the taxi driver; the frying pan scenario is constraining for Pu-239.

[e] The exposures shown are for slag, but the derived levels are for RSM release from the controlled melter.

[f] Because of its long half-life (2×10^5 years), Tc-99 is not considered for Tier C release.

appropriate for offgas/dust were used in the calculation. The efficiency of the baghouse filtration system was assumed to be 99.95% (actual efficiencies could be higher), except for tritium releases to which filtration does not apply. The CAP88-PC code (USEPA 1992) was used with the scenario assumptions given in Appendix C. Doses from emissions from processing RSM in a commercial smelter are lower than doses from other scenarios and, therefore, do not constrain release levels.

Population doses from smelter emissions are presented in Table 5.6 for a 50,000 t RSM ingot throughput with a 1 Bq/g concentration of each nuclide. The doses were estimated with the CAP88-PC code and the same parameters used for the individual dose calculation. Doses from air emissions are generally orders of magnitude lower than those from worker exposures or public exposures from product end-use scenarios.

5.2.2.4 Doses to Workers and the Public from RSM Transportation

Radiological risks from transporting RSM would occur regardless of whether the metal were shipped for disposal or for decontamination and recycling. Doses would mainly result from gamma radiation exposure during routine shipment of strong gamma emitters such as Co-60. Alpha and beta radiation would be contained by the packaging in which the metal was transported. Current U.S. regulations (USNRC 1993b) specify dose limits equivalent to 100 μSv/h at 1 m from the package surface and 20 μSv/h at the crew compartment. RSM shipments with activity levels consistent with public (including smelter and mill workers) exposure scenario dose constraints would usually result in an external radiation field much lower than the regulatory limits for transportation. Detailed evaluation indicated that external dose for a typical RSM shipment is about two orders of magnitude less than U.S. regulatory limits (Chen et al. 1995).

TABLE 5.6 Summary of Public Doses Associated with Gaseous Radioactive Emissions from a Steel Smelting Plant[a]

Nuclide Category	Representative Nuclide	Dose to Maximally Exposed Individual[b] (μSv/yr)	Population Dose[c] (person-Sv/yr)
Alpha	Ac-227	3.5×10^{-3}	4.8×10^{-4}
	Am-241	3.0×10^{-3}	4.2×10^{-4}
	Pu-239	2.0×10^{-3}	2.6×10^{-4}
	U-238	6.7×10^{-4}	9.2×10^{-5}
Beta	Sr-90	6.2×10^{-4}	1.6×10^{-5}
	Tc-99	1.1×10^{-3}	3.4×10^{-5}
Gamma	Co-60	2.8×10^{-4}	8.2×10^{-6}
	Cs-137	5.4×10^{-2}	5.0×10^{-5}
	Zn-65	3.1×10^{-3}	8.3×10^{-5}
Volatile nuclides	H-3	3.8×10^{-7}	4.6×10^{-8}
	I-129	5.9×10^{-2}	1.0×10^{-3}
Radon	Ra-224	1.9×10^{-3}	2.8×10^{-4}
	Ra-226	1.3×10^{-3}	1.9×10^{-4}
	Th-232	1.1×10^{-3}	8.3×10^{-5}

[a] Based on 50,000 t/yr RSM throughput with 1 Bq/g of each nuclide. Calculations were performed with the CAP88-PC code (USEPA 1992) assuming an off-gas filtration efficiency of 99.95% for particulates and the partitioning factors given in Appendix C, Table C.4.

[b] Maximally exposed individuals are located 100 to 700 m from the stack, depending on the radionuclide.

[c] Population includes public within an 80-km radius of the plant.

The risks of accident-free transport at the regulatory dose limits were calculated with the RADTRAN code using the default values (e.g., speed) for rural, suburban, and urban locations (Neuhauser and Kanipe 1993). Risks for routine operations include those affecting the population (residents) along the route, passengers sharing the road, the population at vehicle stops, and vehicle crew members. Shipping 50,000 t of RSM for a distance of 100 km in 20 t-shipments would result in a maximum individual dose of 2×10^{2} μSv/yr (lifetime cancer fatality risks of 1×10^{-5}) for the crew. This assumed 2,000 hours per year of driving time per crew member. Health risks are calculated using the health risk conversion factors from ICRP-60 (ICRP 1991). For the crew and general public, the collective dose from transporting 50,000 t a distance of 100 km is 2×10^{-2} person-Sv, with estimated cancer fatality risks of 8×10^{-4}. The recycling alternative is assumed to involve two transportation

activities: scrap from the originating site to the controlled melter and decontaminated metal in ingot form to a commercial melter or mill.

5.2.2.5 Doses from Disposal Alternatives

Two disposal alternatives were evaluated, disposal at an unrestricted landfill of RSM released for unrestricted reuse or recycle and disposal of residuals from RSM smelting at a dedicated LLW site. Only individual doses were estimated; population doses were not calculated because the uncertainties associated with site-specific parameters — such as leaching of wastes into groundwater, groundwater transport, distance to and size of the nearest aquifer, and type and extent of public use of the aquifer — preclude meaningful estimates.

The unrestricted disposal scenario assumed a pile of RSM 0.5 m thick and 11,400 m^2 in area (corresponding to a 50,000-t mass) buried in a public landfill. This pile was assumed to be mixed with another 0.5 m of soil (1 m total thickness) and the mixture covered with a 0.5 m thickness of clean soil. The concentration of metal assumed in the scenario is very conservative for reusable RSM since the objects are likely to be disposed of in many landfills over an extended time period. There is additional conservatism in this scenario with regard to products of unrestricted recycle, since all of the activity would be volumetric. Half of the metal mass is assumed to comprise pieces with surface contamination (at 1 Bq/cm^2) with an average thickness of 10 cm and half pieces with volumetric contamination (at 1 Bq/g). The release mechanism in soil would be through metal corrosion, followed by leaching of contaminants to the groundwater. Complete removal of nuclides to soil was assumed to take place within one year after disposal for surface contamination and 100 years for volumetric contamination. The landfill was assumed to have restricted access for 30 years following disposal and to be released for public use thereafter, at which time a member of the public would reside at the landfill site and utilize well water from the site as the only drinking water source. Individual doses calculated with the RESRAD code (Yu et al. 1993[b]) are presented in Table 5.7. For surface contamination, doses for most nuclides are less than 10 μSv/yr. For volumetric contamination, doses are generally on the order of 10 μSv/yr. The relatively high doses of some nuclides, such as Ra-226 or I-129, indicate that they require activity levels less than 1 Bq/g to reduce doses to 10 μSv/yr.

Doses from disposal of RSM residuals from smelting at a LLW site were not specifically calculated. However, any type of LLW must meet existing disposal regulations (such as 10 CFR 61 [USNRC 1993a]). Health risks from RSM residuals disposal are likely to be lower than those estimated for LLW in general because nuclides would be bound in slag and dusts are likely to be solidified prior to disposal. EG&G Idaho, Inc. (1987) indicates that doses from a LLW disposal facility to the maximally exposed individual, an intruder, range from 35 to 200 μSv/yr. Individual public doses must not exceed the regulatory limit of 1 mSv/yr (ICRP 1991; 10 CFR 20 [USNRC 1990]).

TABLE 5.7 Estimated Public Individual Doses for Unrestricted Disposal[a] at a Landfill

Nuclide Category	Representative Nuclide	Individual Dose[b]		Derived Activity Level[c]	
		Surface Contamination (μSv/yr)	Volume Contamination (μSv/yr)	Surface Contamination (Bq/cm^2)	Volume Contamination (Bq/g)
Alpha	Ac-227	1.4×10^{0}	4.0×10^{1}	7.1×10^{0}	2.5×10^{-1}
	Am-241	4.4×10^{-1}	1.2×10^{1}	2.3×10^{1}	8.3×10^{-1}
	Pu-239	5.0×10^{-1}	1.3×10^{1}	2.0×10^{1}	7.7×10^{-1}
	U-238	6.9×10^{-2}	1.8×10^{0}	1.4×10^{2}	5.6×10^{0}
Beta	Sr-90	2.6×10^{0}	7.0×10^{1}	3.9×10^{0}	1.4×10^{-1}
	Tc-99	0.0	1.3×10^{1}	-[d]	7.7×10^{-1}
Gamma	Co-60	1.3×10^{-2}	3.3×10^{1}	7.7×10^{2}	3.0×10^{-1}
	Cs-137	2.5×10^{-1}	3.0×10^{0}	4.0×10^{1}	3.3×10^{0}
	Zn-65	0.0	0.0	-[d]	-[d]
Volatile nuclides	H-3	0.0	1.5×10^{0}	-[d]	6.7×10^{0}
	I-129	0.0	3.8×10^{3}	-[d]	2.6×10^{-3}
Radon	Ra-226	4.5×10^{2}	1.3×10^{4}	2.2×10^{-2}	7.7×10^{-4}
	Th-232	6.3×10^{0}	1.7×10^{2}	1.6×10^{0}	5.9×10^{-2}

[a] Doses are based on RESRAD calculation assuming 50,000 t RSM disposal in a single mass at one landfill. A residential scenario is assumed at the landfill after 30 years of restricted access following the disposal.

[b] Based on an assumed surface concentration of 1 Bq/cm^2 and an assumed volume concentration of 1 Bq/g at the time of disposal.

[c] Based on an annual dose of 10 μSv/yr.

[d] Surface contaminant does not show long-term effects because of a high rate of leaching, transport, and accompanying dilution.

5.2.3 Derived Release Levels

Activity levels based on a 10 μSv/yr dose limit have been derived from the individual dose estimates discussed in Section 5.2.2. For surface contaminated objects released for reuse, the derived activity levels shown in Table 5.4 are generally consistent with existing standards (e.g., Regulatory Guide 1.86 [USNRC 1974]) and with the derived levels in Safety Series No. 111-P-1.1 (IAEA 1992), except that radon emissions were not previously accounted for. Consideration of radon emission results in relatively large dose estimates for nuclides with radon in their decay chains. However, these estimates have large uncertainty ranges because of the uncertainty regarding the radon emanation rate from surface contamination. Dose buildup from decay product ingrowth is a concern for these nuclides and has been considered in deriving Tier A release levels. If radon gas and its progeny were included in deriving levels based on 10 μSv/yr, radionuclides such as Ra-226 would have such low release levels that it would be difficult, if not impossible, to measure compliance. For alpha emitters,

the controlling parameter appears to be the contaminant emission rate (i.e., surface resuspension factor). For beta emitters, the ingestion rate is dominant. Empirical data for these key factors are limited, particularly pertaining to surfaces treated by current decontamination techniques. Continued research efforts, especially in experimental areas, are needed to improve upon the existing information.

Derived activity levels for constraining scenarios for unrestricted recycle of volumetrically contaminated ingots and prescribed initial uses are summarized in Table 5.8. The derived levels are based on a 50,000-t/yr RSM throughput and, for recycle in a commercial smelter, incorporate nuclide partitioning factors and an RSM dilution factor of 1:10. Release levels for ingot recycle in a mill and for prescribed initial use were derived from a RSM activity concentration without dilution after release and are constrained by public exposure to products. Slag product exposure scenarios were analyzed for the commercial smelter recycle case but were not constraining.

For recycle in a smelter, release levels for all nuclides are constrained by commercial smelter worker exposures. This is also true if the RSM throughput of a commercial smelter is 10,000 t rather than 50,000 t. The only case in which public dose is nearly as constraining as worker dose is the Co-60, taxi driver scenario. Release levels for direct commercial milling of ingots from the controlled melter are constrained by public, rather than worker, exposures. Except for Pu-239, which is higher than for recycling by remelting, the release levels for direct milling of ingots are of the same order of magnitude as for melting. This indicates that levels derived for recycling in a commercial smelter would be sufficiently protective, even if ingots that were released for remelt were directly milled.

TABLE 5.8 Derived Radioactive Scrap Metal Release Levels for Unrestricted Recycle and Prescribed Initial Use, Showing the Constraining Scenarios[a]

	Unrestricted Recycle in Commercial Melt		Unrestricted Recycle in Commercial Milling		Prescribed Initial Use	
Representative Nuclide	Derived Levels (Bq/g radioactive scrap metal)	Constraining Scenario	Derived Levels (Bq/g radioactive scrap metal)	Constraining Scenario	Derived Levels (Bq/g radioactive scrap metal)	Constraining Scenario
Ac-227	2×10^{-1}	Slag worker	4×10^{-1}	Taxi driver	-[b]	-
Am-241	5×10^{0}	Slag worker	2×10^{0}	Taxi driver	-[b]	-
Pu-239	7×10^{0}	Slag worker	1×10^{1}	Frying pan	-[b]	-
U-238	5×10^{0}	Slag worker	4×10^{0}	Taxi driver	-[b]	-
Sr-90	2×10^{1}	Slag worker	9×10^{1}	Taxi driver	3×10^{2}	Public - building
Tc-99	1×10^{3}	Slag worker	2×10^{3}	Taxi driver	-[b]	-
Co-60	7×10^{-1}	Caster	1×10^{-1}	Taxi driver	5×10^{-1}	Public - building
Cs-137	2×10^{-1}	Slag worker	5×10^{-1}	Taxi driver	3×10^{0}	Public - building
Zn-65	3×10^{1}	Slag worker	7×10^{-1}	Taxi driver	3×10^{0}	Public - building

[a] Levels are constrained by 10 μSv/yr and are based on 50,000 t throughput.

[b] Tier C is not applicable to nuclides with long half-lives, e.g., Tc-99 is not considered for Tier C because its half-life is 2×10^{5} years.

Derived levels for prescribed initial uses are one order of magnitude less restrictive than those for unrestricted recycle by melting for Sr-90 and Cs-137 because of greater exposure distance and shorter exposure duration under the Tier C scenarios. Overall, however, the prescribed-initial-use applications do not provide much advantage in terms of avoiding public exposure. The advantage of Tier C is in avoiding commercial worker doses. Investigation of other Tier C applications is warranted where public access would be restricted (thereby substantially reducing population dose), such as in ships or military uses. The derived level for Co-60 is about the same for both Tiers B and C because there is less uncertainty regarding parameter values for external exposure than for other pathways and Co-60 remains almost entirely in metal after melting.

5.2.4 Other Considerations

Individual dose estimates were calculated for the first year following the release of RSM. Because radionuclides generally decay over time, doses are usually higher in the first year than in subsequent years. However, in some situations, higher doses would develop over time, rendering the first-year dose less constraining. These situations include the effect of years of RSM recycling, which would result in an increasing proportion of RSM in metal stocks over time, and the increase in nuclide concentration in surface contaminated objects resulting from decay product ingrowth (particularly for radon and its progeny). In addition, potential radioactivity reconcentration due to eventual disposal of obsolete RSM products must also be considered.

5.2.4.1 Proliferation of Radioactive Scrap Metal in the Metal Supply

Continued recycling of RSM will very gradually increase the percentage of RSM in the common metal scrap returned to smelters, which will effectively decrease the dilution rate for RSM over time. The resulting buildup of radioactivity in a typical consumer product for a recycling practice is estimated to be about 25% over 40 years (IAEA 1992). Considering the level of uncertainty in estimated doses and the very low doses associated with undiluted RSM, this increase is quite insignificant.

5.2.4.2 Decay Product Ingrowth

The doses calculated in this study have included the dose contributions from decay product nuclides with half-lives of less than one year. For most radionuclides, this is sufficient to account for potential dose buildup from decay product ingrowth.

For some nuclides, however, the potential buildup by ingrowth continues beyond the first year. This issue applies specifically to the reuse scenario of Tier A for surfaces contaminated by radon emitters. For example, Ra-228 (a nuclide in the thorium series with a half-life of 5.8 years) decays to Th-228 (half-life of 1.9 years), which in turn emits Rn-220 in the subsequent decays. Variation over time in the total dose from the Ra-228 and Th-228

decay chains is shown in Figure 5.2; the dose peaks at about 1.8×10^4 μSv/yr in less than five years. In contrast, the first-year dose for the room occupancy scenario with surface contamination is only about 2×10^3 μSv/yr, a factor of 10 less than the peak value. Of course, not all the radon parent nuclides have such a large buildup, but because of the potential dose increase over time, the dose should be estimated with a time frame specified for identifying the maximum doses, rather than just the first-year dose. In this study, doses are presented for the maximum year. For surface-contaminated objects a 30-year period of building occupancy and 10 years of tool use are considered.

5.2.4.3 Reconcentration of Radioactivity at Disposal Sites

Obsolete scrap will eventually be discarded to landfills where RSM activity could be reconcentrated. Reconcentration due to disposal should not be a serious concern for these tiers, however, since the dilution of obsolete RSM products in landfills is likely to be orders of magnitude greater than that assumed in the RSM landfill scenario. In addition, the period of metal end use before disposal will allow reduction of some activity levels by decay. Therefore, reconcentration of activity is unlikely to reach levels that merit concern.

When doses and derived levels for volumetrically contaminated recycle products under the landfill scenario assuming disposal of 50,000 t of RSM (shown in Table 5.7) are compared with those for reusable, surface-contaminated objects (Table 5.4), the levels for reuse of surface-contaminated objects are either lower or comparable and would therefore be protective even if the objects were disposed of, except for Sr-90. For volumetrically-contaminated object reuse, all of the release levels for alpha and beta emitters are substantially less constraining than levels for the landfill scenario. Release levels for volumetrically-contaminated ingots under Tiers B or C (Table 5.5), however, are generally less constraining than those derived for the landfill scenario. Derived activity levels for

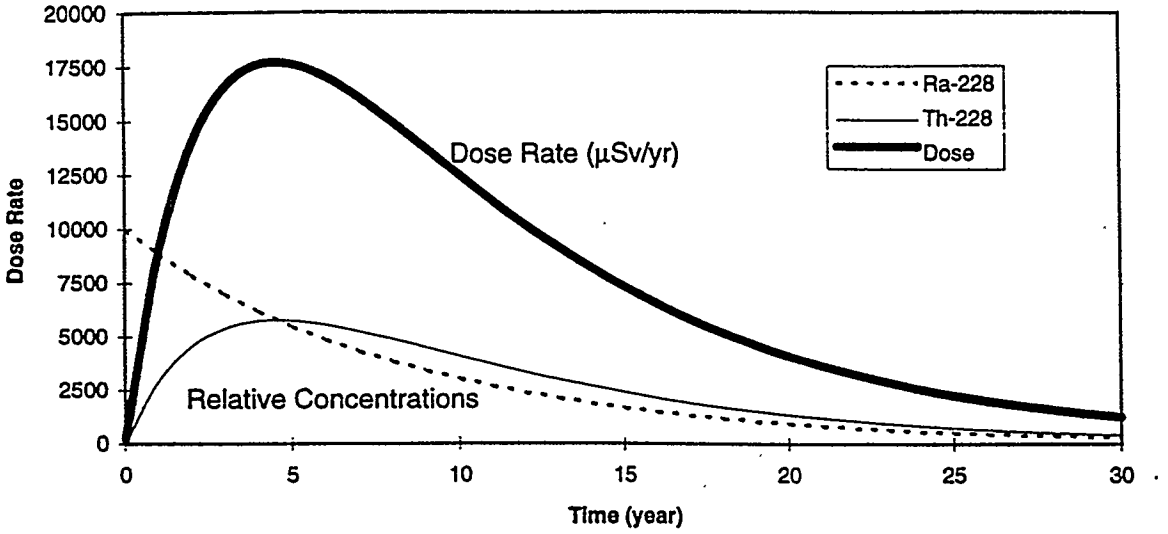


FIGURE 5.2 Variation in Total Dose Rate over Time for a Radon Parent Nuclide

Tier B are generally at least two orders of magnitude higher than those for the landfill scenario. Thus, the derived release levels for volumetrically-contaminated metal to be reused or recycled are not found to be protective if 50,000 t were disposed of under the very conservative assumptions of this analysis. Such an event is extremely unlikely.

5.2.4.4 Uncertainty Analysis

A simulated probabilistic analysis (discussed in Appendix C) was conducted to evaluate the advantages of this approach for standard development. It provides a means of explicitly accounting for the variability and uncertainty in key parameter values. However, currently available data for some of the key parameters affecting dose estimates for metal recycling activities are inadequate for the purposes of probabilistic analysis. Further characterization of these parameters will be required to obtain the advantages this approach offers for avoiding costly conservatism.

5.2.5 Summary of Radiological Health Impact Analysis

Radiological risks from either RSM recycling or reuse are quite low. Release levels for the proposed tiers were derived on the basis of limiting the public dose to 10 μSv/yr, so cancer fatality risks to individual members of the public, including industrial workers, from unrestricted recycling operations would be less than 10^{-6}. Radiological risks to nuclear workers and of the public as a result of RSM disposal were assumed not to exceed regulatory limits of 10^{-3} for workers and 10^{-5} for the public. Radiation exposure of truck drivers during RSM transportation would result in individual risks of less than 10^{-5} and public exposure would be negligible.

5.3 NONRADIOLOGICAL HEALTH EFFECTS

This section describes potential nonradiological impacts associated with recycling RSM. Impacts may arise from decontamination activities, including metal melting in a controlled facility, that are above and beyond what would occur if the RSM were being disposed of. The impacts may also result from work place or transportation accidents and from emissions from commercial smelters after release of the decontamination RSM. These impacts include health effects to workers (Section 5.3.2) and the general public (Section 5.3.3).

Of the recycling process activities discussed in Section 5.1, only decontamination activities would be an incremental source of nonradiological health risks from using RSM instead of uncontaminated scrap. These operations are likely to be conducted in an enclosed facility, for which worker exposures would be the primary concern. The chemical exposure and accident risks associated with commercial smelting of RSM would be similar to those from using uncontaminated scrap. This section addresses the nonradiological risks associated with decontamination, smelting, and metal transportation activities.

5.3.1 Methodology

The nonradiological health impacts that could result from human exposures associated with recycling RSM include both carcinogenic and noncarcinogenic effects. The methodology used to estimate these effects is as follows. The risk of developing cancer can be calculated by multiplying a person's estimated intake by a standard slope or potency factor. The potential for a noncarcinogenic effect can be indicated by a "hazard index," which represents the sum of the hazard quotients determined for individual contaminants. These hazard quotients are calculated by dividing the dose or intake estimated for a person by the standard reference dose for that contaminant that is generally considered safe or acceptable by the scientific community. The toxicity values applied in this assessment to estimate health effects that could result from chemical intakes were developed by the U.S. Environmental Protection Agency.

The following general equation is used to estimate contaminant intakes:

$$I = (C \times CR \times EF \times ED)/(BW \times AT) \quad , \tag{5.1}$$

where

I = intake of the chemical (mg/kg-day),

C = concentration of the chemical in an environmental medium (e.g., air or water) (mg/m^3 in air or mg/L in water),

CR = contact rate of the exposed individual with the medium (e.g., m^3/day or air or L/day of water),

EF = exposure frequency (days/year),

ED = exposure duration (years),

BW = body weight (kg), and

AT = averaging time (days).

Appropriate values for these parameters are determined by the specific exposure scenario, pathway, and receptor.

5.3.2 Workers

5.3.2.1 Decontamination Chemical Exposures

Inhalation of airborne contaminants within the decontamination facility is the primary pathway of concern for workers. To assess the health effects to workers from

chemical exposures during decontamination activities, the following factors are considered: (1) the type of metal being decontaminated, (2) the type of activities, chemicals used, and emissions produced inside the facility; and (3) the type of clothing worn and protective equipment used. Nonradiological health effects are evaluated for the following contaminants: cadmium, chromium, copper, lead, manganese, nickel, uranium, and zinc. Other contaminants are not included because no adverse health effects are expected from related exposures or because standard toxicity values are not available to quantify potential effects even though the chemical is indicated as a carcinogen and/or toxic agent (e.g., lead). The potential health impacts associated with aluminum, iron, and lead inhalation are not quantified because standard toxicity values are not available. The toxicity associated with oral exposure to aluminum and iron is relatively low, and hence their contribution to total health impacts is expected to be low. Although aluminum and iron are somewhat more toxic via the inhalation route, their expected toxicities relative to the other metals for which health impacts can be quantified are relatively low. Lead is both highly toxic and a potential carcinogen, but no standard toxicity values to support quantitative analysis are currently available for this metal.

For this analysis, nonfixed surface contamination is assumed to have been removed from the RSM (e.g., by vacuuming or wiping) at the originating facility before the equipment or structure was dismantled. This assumption is based on the application of good engineering practices to control exposures during the scrap metal collection stage. Thus, the decontamination activities evaluated are those designed to address fixed contamination that can be removed from the surfaces of RSM by methods such as aggressive mechanical removal, electropolishing, chemical dissolution, and metal melting. General process information in the following discussion is summarized from Manion and LaGuardia (1980), Nuclear Energy Agency (1981), International Atomic Energy Agency (1985, 1986, 1987a), Loiselle (1993), and Masaidis (1993). The decontamination processes are first evaluated to assess chemical releases from which to estimate contaminant intakes and health effects. An evaluation of process hazards follows these risk calculations.

Mechanical removal can involve stripping or peeling (e.g., following a latex application), hydrolysing using a high-pressure water wash, or solid abrasive methods such as scraping, wire brushing, spalling, and blasting with sand, glass beads, or dry ice. The solid abrasive methods are most common, and these processes generate airborne emissions in addition to solid residuals. The hydrolysing process generates an aqueous waste, whereas peeling generates solid residuals. It is assumed that workers are not in direct contact with the aqueous waste stream or the solids; thus, the chemical exposure of primary concern for workers during decontamination operations is to airborne contaminants.

Electropolishing is a less common, but effective, decontamination method that uses phosphoric acid as the electrolyte to separate contaminants from the metal. The liquid waste generated by this process is neutralized, and contaminant solids are then removed by conventional processes such as gravity settling or filtration before discharging the effluent. No airborne emissions would be associated with the liquid waste or wet solids, and no

adverse health effects would be expected from phosphates derived from the initial reagent following effluent release.

Chemical dissolution processes are commonly used to decontaminate scrap metal, and the following liquids can be used alone or in combination: organic solvents, alkaline permanganate and alkaline citrate, citric acid and detergents (soap), nitric acid and sodium fluoride, sulfuric acid and hydrogen peroxide, sulfamic acid, hydrochloric acid, and phosphoric acid. Sequestrants such as ethylenediamine tetraacetic acid can also be used to maintain metals in solution during the decontamination step. Although organic solvents are typically used to remove surface organic contamination such as oil and grease, these solvents are generally not part of the primary RSM decontamination process. These solvents are not used as frequently as the other liquids, and relatively small volumes are involved. Therefore, they are not considered further in this assessment.

The chemical dissolution processes generate liquid wastes that typically are neutralized and then are filtered or settled to remove solids in a process similar to that for electropolishing wastes. The key chemicals associated with the reagent solutions, relative to potential health effects from incidental ingestion, are fluoride, nitrate, and manganese. In addition, certain metals are of concern for dermal exposures. Sulfates and phosphates do not pose a human health threat, nor do citrates or soap. Since humans are not expected to be in extended contact with the liquid wastes, neither incidental ingestion nor dermal exposures are evaluated in this assessment.

The solid wastes generated by decontamination processes are often thermally treated (e.g., in an incinerator or melter) or immobilized (e.g, in a cement, bitumen, polymer, or glass matrix). Liquid wastes are typically treated by standard wastewater treatment processes such as flocculation, precipitation, filtration, ion exchange, and evaporation. Thermal treatment can result in airborne emissions, but nonvolatile chemicals would not be expected to be released from the liquid waste or wet solids. Thus, the airborne pathway is the primary concern for nonradiological exposures associated with thermal treatment.

Workers are assumed to use protective clothing and equipment as needed to limit contact with chemicals within the decontamination facility. For example, cotton coveralls or similar clothing would be worn routinely, and plastic or rubber clothing would be worn when handling acids; these measures would limit dermal contact. Respiratory protective equipment would be worn during any activities resulting in high indoor contaminant levels, and at least face masks would be worn to cover the nose and mouth when appropriate (e.g., when contaminant levels exceed work place standards).

To quantify potential health effects, it is assumed that worker protection standards would be met to limit occupational exposures to indoor particulates. Limiting concentrations for airborne contaminants are taken from the standards and guidelines presented in Table 5.9. The permissible exposure limits identified by the U.S. Occupational Safety and Health Administration (OSHA) for cadmium, trivalent chromium, copper, manganese, nickel,

TABLE 5.9 Occupational Standards and Guidelines for Chemical Contaminants

Contaminant	Occupational Standard/ Guideline[a] (mg/m^3) OSHA PEL[b]	ACGIH TLV[c]	NIOSH REL[d]	Comments
Cadmium	0.005	0.05	–[e]	PEL: All cadmium compounds, including dust and fumes. TLV: Cadmium dusts and salts, as cadmium.
Chromium III	0.5	0.5	0.5	Chromium III compounds, as chromium.
Chromium VI	NA	0.05	0.001[e]	TLV: Water-soluble and certain water-insoluble chromium VI compounds, as chromium. REL: For carcinogenic compounds; for noncarcinogenic compounds, the REL is 0.025 mg/m^3, with a 15-minute ceiling of 0.05 mg/m^3.
Copper	1	1	1	Dusts and mists, as copper. PEL and REL for copper fume is 0.1 mg/m^3; TLV for copper fume is 0.2 mg/m^3.
Lead[f]	0.05	0.15	<0.1	PEL: Inorganic compounds, as lead. TLV: Inorganic dust and fumes, as lead.
Manganese	1	5	5	PEL and REL: Fume, as manganese. TLV: Dust and compounds; TLV for fume is 1 mg/m^3.
Nickel	0.1	0.1	0.015[e]	PEL: Soluble compounds, as nickel; PEL for metallic nickel and insoluble compounds is 1 mg/m^3, as nickel. TLV: Soluble compounds as nickel; TLV for insoluble compounds is 1 mg/m^3.
Uranium	0.05	0.2	0.05	PEL and REL: Soluble compounds, as uranium; PEL and REL for insoluble compounds is 0.2 mg/m^3, as uranium. TLV: Soluble and insoluble compounds, as uranium.
Zinc	5	10	5	REL and PEL: Zinc oxide fume; 15-minute ceiling is 10 mg/m^3. TLV: Zinc oxide dust; TLV for fume is 5 mg/m^3.

Footnotes appear on next page.

TABLE 5.9 (Cont.)

[a] Each comment applies to the PEL, TLV, or REL (defined below), as specified; where no specific designation is noted, the comment applies to all three standards/guidelines; NA means no data are available.

[b] Permissible exposure limit (PEL) of the Occupational Safety and Health Administration (OSHA) (29 *Code of Federal Regulations* Part 1910); PELs are 8-hour time-weighted average (TWA) concentrations.

[c] Threshold limit value (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH 1990); TLVs are 8-hour TWA concentrations.

[d] Recommended exposure limit (REL) of National Institute for Occupational Safety and Health (NIOSH 1990). Unless otherwise noted, RELs are 10-hour TWA concentrations.

[e] Carcinogen; reduce exposure to lowest feasible level.

[f] Lead limits are presented for information purposes; standard USEPA toxicity values are not currently available for quantifying related health effects.

uranium (insoluble compounds), and zinc were used. An OSHA value is not available for hexavalent chromium, so the threshold limit value of the American Conference of Governmental Industrial Hygienists (ACGIH 1990) was used.

Chemical intakes of airborne contaminants by a decontamination worker are estimated with Equation 5.1. The worker is assumed to be exposed 8 h/day, 5 days/week, for 50 weeks over 1 year. This unit duration is used so results can be readily scaled to estimate health effects for other time periods. The worker's inhalation rate is assumed to be 1.2 m^3/h; the body weight is assumed to be 70 kg, which is the standard value for an adult (USEPA 1991). The average daily intake over 1 year is used to estimate noncarcinogenic effects, whereas the estimated annual intake is averaged over a lifetime of 70 years (25,550 days) to estimate cancer risks. These averaging times are different because the reference doses reflect "acceptable daily intakes" for noncarcinogens, whereas the slope factors applied to estimate cancer risks are based on an exposure period of 70 years.

With these conservative assumptions, a worker's lifetime risk of developing cancer from exposures to chemicals over one year of decontamination activities is estimated to be about 1×10^{-3}. To put this result in perspective, about 3×10^{-1} Americans is expected to develop cancer from all causes (American Cancer Society 1992). Thus, the lifetime risk estimated for a decontamination worker is a small fraction (0.3%) of the background cancer rate in the U.S.A. If the worker were exposed over 40 years, the incremental lifetime risk from this workplace exposure would increase to about 10% of the background rate.

The estimated hazard index for the worker exceeds 1, indicating that adverse noncarcinogenic effects could occur if this person were continually exposed to all of the airborne contaminants evaluated in this assessment with each at their individual concentration limits. (Hexavalent chromium is the primary contributor to health impacts.) This risk estimation approach is conservative, but the result is not inconsistent with data for occupational illnesses. For example, an annual occupational illness rate of about 3×10^{-3} has been reported for workers in primary metal industries in the U.S.A. (U.S. Department of Labor 1986).

It is important to note that for these analyses, it was assumed that all metals were present at the maximum permissible concentrations for the entire exposure period and that no inhalation protection measures were taken. It is very unlikely that both assumptions would hold over the full exposure assessment period, especially for 40 years. In regulatory practice, the "allowable" concentrations are adjusted proportionately downward for those chemicals with similar (additive) toxicologic endpoints. When the concentrations of metals exceed their limits, protective measures would be taken to reduce exposures. Therefore, actual health effects for workers are expected to be well below the conservative estimates presented in this assessment.

5.3.2.2 Decontamination Accidents

Workers could also be injured in accidents during decontamination operations. Process hazards associated with the various decontamination methods include water jet misfires during hydrolysing and skin or eye burns from spills or splashes of acid reagents during electropolishing or chemical dissolution processes. In addition, workers could experience common industrial accidents such as falling, being struck or caught by equipment or other objects, being electrocuted, or being burned by a fire or explosion.

The potential for worker injuries and fatalities from accidents can be derived from data for metal industries in the U.S.A. These data indicate that a facility employing 100 workers could expect 13 accidents with injuries per year, and the annual incidence rate of fatalities for the manufacturing industry is about 4×10^{-3}. Of this total, about 20% are attributed to being hit by machinery or other objects, 12% to industrial vehicle or equipment accidents, 10% to fire and explosions, 9% to electrocutions, and 8% to falls (U.S. Department of Labor 1986).

5.3.2.3 Smelting Accidents

For blast furnace and steel mill workers combined, the annual rate of fatalities and major injuries was 6×10^{-2} workers (U.S. Department of Labor 1989), which is equivalent to 4×10^{-4}/t of steel and 7 fatalities or disabling injuries from blast furnace operation for throughput of 50,000 t. The fatality and serious injury rate for iron and steel foundries based on U.S. Department of Labor (1989) statistics is also relatively high, 7.5 for production of 50,000 t of steel.

In conclusion, the likelihood that a worker would incur adverse health effects from exposures to chemical contaminants during RSM operations is expected to be similar to the likelihood of adverse affects associated with similar industrial operations that do not involve radioactive scrap. The potential for accidents and injuries (including from transportation) is expected to be lower in the RSM recycle activities that occur under radiation controls than if the worker were employed in a comparable job requiring similar skills because of the additional precautions taken when managing radioactive materials.

5.3.3 General Public

Health effects of decontamination chemical and smelting emissions exposures from recycling processes are discussed, as well as effects of transportation emissions and accidents. In regard to the finished metal products, the chemical composition of an item manufactured from recycled RSM would be essentially the same as that of a similar item manufactured from uncontaminated scrap. Hence, no incremental chemical exposures or health effects would be associated with the use of such a product.

5.3.3.1 Decontamination Chemical Exposures

Emissions of airborne contaminants from a decontamination facility could also be a source of potential exposure to the general public. However, these emissions would have to be controlled to very low levels in order to meet licensing requirements. A representative analysis of this pathway is not conducted here because it requires defining the following process, control system, and location characteristics: the types and concentrations of contaminants produced, the pollution control systems used, facility stack heights, surrounding terrain, and local and regional meteorology. Although public exposures via the air pathway have not been quantified, health risks should be negligible because highly effective pollution control systems would be used to limit releases from an RSM decontamination facility.

The decontamination activities would result in some secondary wastes that would require disposal, including residuals collected from liquid wastes. However, the quantity of solids generated by decontaminating the RSM would be much smaller than the quantity of solid material that would be directly disposed of if the RSM were not recycled. The primary issue would be the increased concentration of radionuclides in the solids. Because the health impacts of direct disposal of RSM are anticipated to be insignificant (see Section 6.1), the impact of disposing of the relatively minor volume of secondary waste from decontamination activities is also expected to be negligible.

Liquid effluents could also be released from RSM decontamination facilities, depending on the process used, but these releases are assumed to meet the discharge requirements of the locale/country where each facility is situated. Although these releases could be a source of exposure to individuals downstream who use the receiving body of water for drinking and cooking, it is assumed that health protection would be a primary basis for the discharge levels to which the releases would be controlled. Therefore, human exposures to residual contaminants in the receiving water are expected to be negligible.

5.3.3.2 Chemical Exposures from Smelting

During the decontamination process, RSM may be melted in a controlled melt facility. As a result of radiological exposure controls, chemical exposures of radiation workers and the public from these activities are likely to be very low. After release for unrestricted recycling, RSM could be remelted in a commercial smelter, resulting in chemical exposures to commercial metal workers and to the downwind population. The resulting health impacts would be similar to those that occur from routine commercial recycling of scrap in metal production.

Air Emissions from Smelting

The approach taken to assess chemical exposure of the general public from smelting is based on chemical emissions data from steel production (Nriagu and Pacyna 1988). The analysis assumed that 50,000 t of steel would be produced annually to replace disposed RSM.

Emissions from this throughput are reported for the 11 metals that are the "chemical contaminants of concern" for this assessment, which are listed in Table 5.10.

To maintain consistency with the radiological analysis, output from the CAP-88 code (USEPA 1992) for radionuclide emissions was used as the basis for estimating chemical concentrations at relevant receptor locations. This approach is valid because all the chemicals of concern are metals with transport mechanisms similar to those of the radionuclides. A radionuclide with a very long half-life (i.e., Pu-239) was used to model transport of the metal particles. The receptor evaluated represents an individual at the high end of the range of possible exposures.

Exposure pathways considered were particulate inhalation and ingestion of produce grown in contaminated soil. Meat and milk pathways were not included in the analysis because, for the chemical contaminants of concern, intake via these pathways was much less than via inhalation and produce ingestion. For the produce ingestion pathway, chemical-specific plant uptake factors were obtained from Baes et al. (1984) in accordance with USEPA guidance (USEPA 1989a).

Standard USEPA methods (USEPA 1989a), namely, USEPA slope factors and reference doses, were used to assess carcinogenic risk and risk of systemic effects, respectively. A detailed explanation and discussion of this quantitative risk assessment methodology, including definition of terms, can be found in relevant USEPA documents and databases (USEPA 1989a, 1993a,b). The criteria used to evaluate significant risk in this assessment follow USEPA guidelines for Superfund and RCRA sites (USEPA 1990a,b). Summed carcinogenic risks falling in the range of 10^{-6} to 10^{-4} are considered acceptable. For systemic effects, a hazard index of less than one is considered acceptable (hazard index is the sum of intake divided by the reference dose value for each chemical of concern).

The assumptions used to calculate intake — including an inhalation rate of 22 m^3/d by a 70-kg adult; an exposure duration of 24 h/d, 365 days/yr, for 70 years; and all ingested produce homegrown — are conservative overestimates for the general population. Additionally, although some reduction in particulate exposure while indoors is known to occur (Alzona et al. 1979), this reduction in exposure is not included in the intake calculations. Of the contaminants of concern, five (arsenic, cadmium, chromium VI, lead, and nickel) are classified as known or probable human carcinogens via inhalation. Because a slope factor for lead is not available, the carcinogenic risk cannot be calculated at this time. The calculated inhalation carcinogenic risks associated with the upper estimate of steel production emissions range from 7×10^{-7} for cadmium to 1.5×10^{-4} for chromium, with a sum risk of 1.7×10^{-4}. Details of the estimates are shown in Table 5.10.

The majority of chromium dust released from steel production is in the form of noncarcinogenic chromium III; also, of the total U.S.A. chromium emissions from all sources, 32% is in the form of chromium VI (Agency for Toxic Substances and Disease Registry 1989). Therefore, 32% of the emissions were assumed to be chromium VI in calculating risk, although this is probably an overestimate of the chromium VI releases from steel and iron manufacturing.

TABLE 5.10 Intakes and Risks Associated with the Inhalation Pathway for Smelter Emissions[a]

Chemical Contaminant of Concern	Emission Rate (kg/yr)	Maximum Air Concentration (mg/m^3)	Maximum Intake[b] (mg/kg/d)	Chronic Inhalation Slope Factor[c] $(mg/kg/d)^{-1}$	Chronic Inhalation Reference Dose[c] (mg/kg/d)	Lifetime Carcinogenic Risk Range[d]	Hazard Quotient Range[d]
Antimony	0.25-5.0	8.9×10^{-8}	2.8×10^{-8}	ND	ND	–	–
Arsenic	25-175	3.1×10^{-6}	9.8×10^{-7}	15	ND	2.1×10^{-6} to 1.5×10^{-5}	–
Cadmium	2.0-20	3.6×10^{-7}	1.1×10^{-7}	6.3	ND	7.0×10^{-8} to 7.0×10^{-7}	–
Chromium[e]	200-2,000	3.6×10^{-5}	3.6×10^{-6}	42	ND	1.5×10^{-5} to 1.5×10^{-4}	–
Copper	10-200	3.6×10^{-6}	1.1×10^{-6}	ND	ND	–	–
Lead	75-1000	1.8×10^{-5}	NA	ND	ND	–	–
Manganese	75-2,000	3.6×10^{-5}	1.1×10^{-5}	ND	0.00011	–	0.0037 to 0.10
Nickel	2.5-500	8.9×10^{-6}	2.8×10^{-6}	0.84	ND	1.2×10^{-8} to 2.3×10^{-6}	–
Selenium	0.05-0.15	2.7×10^{-9}	8.4×10^{-10}	ND	ND	–	–
Vanadium	5.0-100	1.8×10^{-6}	5.6×10^{-7}	ND	ND	–	–
Zinc	500-2,250	4.0×10^{-5}	1.3×10^{-5}	ND	ND	–	–
Total	NA	NA	NA	NA	NA	1.7×10^{-5} to 1.7×10^{-4}	0.0037 to 0.10

[a] Emission rate obtained from Nriagu and Pacyna (1988) and assumed annual production rate of 50,000 t. Air concentrations calculated by using CAP-88 (USEPA 1992). Emission rate range and range of carcinogenic risk and hazard quotients reported; air concentrations and intake levels given only for upper end of range. NA = not applicable; ND = not available; – = cannot be calculated.

[b] Intake calculated assuming 22-m^3/day inhalation rate, 70-kg body weight for 70-year exposure; can be obtained by multiplying air concentration by factor of 0.314.

[c] Slope factor and reference dose values obtained from USEPA (1993a,b).

[d] Carcinogenic risk calculated as intake multiplied by slope factor; hazard quotient calculated as intake divided by reference dose (USEPA 1989a).

[e] Chromium emissions assumed to be composed of 32% chromium VI (carcinogenic); therefore, intake value is multiplied by a factor of 0.32.

The individual risk from lead exposure cannot be calculated at this time, but the risk level is relatively low. The calculated air concentration (i.e., 0.018 $\mu g/m^3$) is about 100 times lower than the 1.5 $\mu g/m^3$ 90-day average mandated as the National Ambient Air Quality Standard under the Clean Air Act (40 CFR 50.12).

Only manganese currently has an inhalation reference dose available from the USEPA (1993b). For manganese, the hazard quotient (intake divided by reference dose) is approximately 0.1, which indicates that the exposure would be about 10 times less than the level of concern for systemic toxicity.

Inhalation reference dose data are unavailable for the other chemical contaminants of concern. However, because the predicted daily intakes from inhalation are generally so low, it is unlikely that systemic toxicity estimates would be significant. This statement is based on currently available inhalation reference doses, which generally range from 10^{-5} to almost 1 mg/kg per day (USEPA 1993a,b).

For the produce ingestion pathway, only arsenic and lead (of the contaminants of concern shown in Table 5.11) are considered potentially carcinogenic when ingested by humans. Risk from arsenic via this pathway is within the range considered acceptable, ranging from 8.3×10^{-7} to 5.8×10^{-6}. No slope factor or reference dose values are available for lead; however, the predicted soil concentration of 0.42 mg/kg is much less than the 500 mg/kg cleanup level for Superfund sites (USEPA 1989b).

Except for lead, oral reference doses are available for all the chemical contaminants of concern. Calculation of hazard quotients indicated that systemic toxicity was not of concern for the produce ingestion pathway (i.e., all hazard quotients were far less than one).

Smelting Residuals

Recycling RSM involves melting materials in foundries or steel mills that release residues to the environment. Some of the chemicals comprising these residues have been found to be injurious to human health, especially those from nonferrous metal processing. In steel making, the concentration of toxic chemicals in residues is generally very low, so that human health risks are negligible.

The USEPA recently evaluated wastes associated with iron and steel furnaces to determine whether they should be regulated as hazardous (USEPA 1990c). For this evaluation, possible carcinogenic risks and noncarcinogenic health effects for the maximally exposed individual were estimated from chronic exposures to contaminants released to groundwater, surface water, and air.

The basic oxygen furnace melts some combination of pig iron, scrap, and/or direct-reduced iron and is used in about 60% of steelmaking facilities. The electric arc furnace is used in most of the remainder of the facilities, and scrap is the predominant feed material.

TABLE 5.11 Intakes and Risks Associated with the Produce Ingestion Pathway for Smelter Emissions[a]

Chemical Contaminant of Concern	Emission Rate (kg/yr)	Plant Uptake Factor[b]	Maximum Soil Concentration (mg/kg)	Maximum Plant Concentration[b] (mg/kg)	Maximum Intake[c] (mg/kg/d)	Chronic Oral Slope Factor[d] $(mg/kg/d)^{-1}$	Chronic Oral Reference Dose[d] (mg/kg/d)	Lifetime Carcinogenic Risk Range[e]	Hazard Quotient Range[e]
Antimony	0.25-5.0	0.03	2.1×10^{-4}	6.3×10^{-6}	4.8×10^{-8}	ND	0.0004	–	0.000006 to 0.00012
Arsenic	25-175	0.006	7.3×10^{-3}	4.4×10^{-5}	3.3×10^{-7}	1.75	0.0003	8.3×10^{-8} to 5.8×10^{-7}	0.00016 to 0.0011
Cadmium	2.0-20	0.15	8.3×10^{-4}	1.3×10^{-4}	9.9×10^{-7}	ND	0.001	–	0.000099 to 0.00099
Chromium[f]	200-2,000	0.0045	8.3×10^{-2}	3.8×10^{-4}	9.1×10^{-7}	ND	0.005	–	0.000018 to 0.00018
Copper	10-200	0.25	8.3×10^{-3}	2.1×10^{-3}	1.6×10^{-5}	ND	0.037	–	0.000022 to 0.00043
Lead	75-1000	NA	4.2×10^{-2}	NA	NA	ND		–	–
Manganese	75-2,000	0.05	8.3×10^{-2}	4.2×10^{-3}	3.2×10^{-5}	ND	0.1	–	0.000011 to 0.00032
Nickel	2.5-500	0.06	2.1×10^{-2}	1.3×10^{-3}	9.9×10^{-6}	ND	0.02	–	0.0000024 to 0.00049
Selenium	0.05-0.15	0.025	6.3×10^{-6}	1.6×10^{-7}	1.2×10^{-9}	ND	0.005	–	8.1×10^{-8} to 2.4×10^{-7}
Vanadium	5.0-100	0.003	4.2×10^{-3}	1.3×10^{-5}	9.9×10^{-8}	ND	0.007	–	0.0000007 to 0.000014
Zinc	500-2,250	0.9	9.4×10^{-2}	8.4×10^{-2}	6.4×10^{-4}	ND	0.3	–	0.00047 to 0.0021
Total	NA	NA	NA	NA	NA	NA	NA	8.3×10^{-7} to 5.8×10^{-6}	0.0009 to 0.0063

Footnotes appear on next page.

TABLE 5.11 (Cont.)

[a] Emission rate obtained from Nriagu and Pacyna (1988) and assumed annual production rate of 50,000 t. Soil concentrations calculated by using CAP-88 and assuming 15-cm mixing depth and soil density of 1.6 g/cm^3. Emission rate range and range of carcinogenic risk and hazard quotients reported; air concentrations and intake levels given only for upper end of range. NA = not applicable; ND = not available; – = cannot be calculated.

[b] Plant uptake factors obtained from Baes et al. (1984); plant concentration equals soil concentration multipled by uptake factor.

[c] Intake calculated assuming ingestion rate of 0.53 kg/day and body weight of 70 kg.

[d] Slope factor and reference dose values obtained from USEPA (1993a,b).

[e] Carcinogenic risk calculated as intake multiplied by slope factor; hazard quotient calculated as intake divided by reference dose (USEPA 1989a).

[f] Chromium emissions assumed to be composed of 32% chromium VI (carcinogenic); therefore, intake value is multiplied by a factor of 0.32.

In the basic oxygen process, pure oxygen is injected into molten metal to oxidize carbon, silicon, and other reactive metals. Wastes from these processes include slag and furnace gases, which are passed through air pollution control devices (dry collectors or wet scrubbers) to generate dust and/or sludge. The slag may contain oxides of silicon, aluminum, calcium, magnesium, and trace elements and fused oxides (including those of iron and manganese) combined with calcium silicates and ferrites. Dust/sludge (and uncaptured emissions) can contain metals such as arsenic, lead, nickel, and selenium in addition to organic compounds such as benzene and formaldehyde. Health effects associated with individual constituents of the residuals are described in Appendix E.

To assess potential health and environmental impacts associated with these wastes, the USEPA evaluated the intrinsic hazard of chemicals in the wastes and applied screening criteria to identify key contaminants. The intrinsic hazards were evaluated by testing the slags and the air pollution control dusts/sludges for corrosivity, reactivity, ignitability, and toxicity. Results indicated that the slags were not hazardous, and in fact these slags are commonly crushed for use as aggregate. For the dusts/sludges, the concentration of selenium in a small number of individual samples exceeded the regulatory level for toxicity (which is more appropriately assessed on the basis of multiple samples). For iron blast furnaces, the concentration of lead also exceeded the toxicity limit in a small number of individual samples.

The release and transport of key contaminants associated with steelmaking wastes were then evaluated, considering their persistence and mobility as well as potential volatilization (e.g., of organic contaminants) and leaching. To assess exposures, conservative assumptions were used to estimate intakes from routine inhalation of airborne contaminants, incidental ingestion of soil containing deposited contaminants (accounting for rates of soil ingestion by children), and ingestion of contaminated water. For example, it was assumed that (1) the airborne concentration of respirable particles (including windblown contaminants) equals 50 $\mu g/m^3$ (the limit for particulate matter per the national ambient air quality standard), and the contaminant concentration in those particles equals its concentration in the given waste; (2) two liters of contaminated water is ingested per day; and (3) an individual is exposed for 70 years. Conservative assumptions were also applied to estimate risks; for example, chromium was assumed to be present as the toxic (hexavalent) form. A cancer incidence risk level of 1×10^{-5} was the screening criterion.

For human exposures to airborne particulates, the key contaminants for slag are arsenic, chromium, manganese, and nickel; those for dust/sludge are arsenic, cadmium, and chromium. In general, the large size of slag fragments (most are >100 μm in diameter) limits the potential for downwind exposures. Only particles <100 μm are reasonably transportable; only those less than 30 μm can be transported considerable distances; and only those <10 μm are respirable. Thus, exposures to slag particles are less likely than exposures to dust/sludge particles. The location of receptors relative to a facility is the primary factor in determining the potential significance of exposures.

For slag, airborne arsenic, chromium, and nickel were identified as potential contributors to a cancer risk above 1×10^{-5}, and inhalation of airborne manganese could

result in noncancer health effects. Potential noncancer health effects from incidental soil ingestion were identified for arsenic, chromium, and thallium, and arsenic ingestion could account for a cancer risk above 1×10^{-5}. However, given that much of the slag would exceed respirable size, that the hexavalent form typically accounts for only about 30% of total chromium, and that receptors were assumed to be closer than is typical for such facilities, these risk values are considerable overestimates. If slag leachate were released to a drinking water supply and diluted less than tenfold, long-term ingestion could result in noncancer health effects from antimony, arsenic, lead, and barium; arsenic could also account for a risk above 1×10^{-5}. These risk values are considered overestimates of potential impacts because of the conservative assumptions used and the likelihood of greater dilutions.

For the dust/sludge solids from furnace air pollution control devices, antimony, arsenic, lead, and thallium are indicated as potential contributors to noncarcinogenic health effects from incidental ingestion; arsenic could also account for a cancer risk above 1×10^{-5}. An inhalation risk above this level is indicated for arsenic, cadmium, and chromium. (The screening-level results for these solids are based on conservative assumptions regarding the respirable fraction and contaminant composition, as previously described for the slag components.) If leachate from these solids were diluted less than tenfold by a receiving water body, long-term ingestion could result in noncancer health effects from antimony, arsenic, cadmium, fluoride, lead, manganese, selenium, thallium, and zinc; arsenic could also account for a risk above 1×10^{-5}. As described above for the slags, these values are considered overestimates of potential impacts, and they can also be mitigated by site conditions.

The key contaminants in regard to water supply impacts for slag are arsenic, mercury, fluoride, and molybdenum. The key contaminants for dust/sludge solids from air pollution control devices are arsenic, chromium, fluoride, cadmium, mercury, molybdenum, and selenium. The likelihood of adverse impacts to groundwater from these contaminants is low where certain mitigating conditions exist. These conditions include the presence of clayey soils, a relatively low net groundwater recharge (8-15 cm/yr), the presence of confining layers, and relatively deep (15-23 m) and large aquifers (with large dilution volumes). For the smaller dust/sludge solids, the contaminants are somewhat more available for leaching, and the potential for release, transport, and exposure via ranged from low to fairly high.

The likelihood of adverse impacts to surface water from slag is generally low because of the small fraction of erodible-size solids ($\leq$0.1 mm) and can be further reduced by runon/runoff controls. The potential for significant exposure to contaminants released from slag solids via the surface water pathway was found to be moderate at most. For dust/sludge solids, the smaller particle size (<0.02-2 mm) translates to greater susceptibility to overland transport. Thus, potential impacts could result from uncontrolled placement of this waste (e.g., depending on a facility's proximity to a drinking water source).

From the risk assessment, available data identified no cases of danger to human health or the environment from iron blast furnaces or steel furnaces. In addition, relatively few samples of air pollution control dust/sludge solids from these furnaces exhibited toxicity, and those few were generally at levels just above the regulatory limit. Although exposures

can occur via ingestion and inhalation, facility engineering controls and population distance combine to limit the potential for adverse impacts.

5.3.3.3 Transportation Accidents

The recycle alternative would probably require transportation of RSM from the source facility to the site of the decontamination facility and controlled smelter. Disposal of RSM residuals would also require shipment by truck or rail to the LLW disposal site. All transport is assumed to occur by truck. The RSM ingot would then be transported to a commercial smelter and from there would enter normal manufacturing and distribution channels. Risks associated with vehicle operation (independent of cargo type) include traffic accident fatalities and potential cancer fatalities from vehicle exhaust emissions.

On the basis of accident fatality rates for combination trucks on interstate highways in the U.S.A. (Saricks and Kvitek 1991), a total of 5×10^{-3} fatalities would be expected for recycling 50,000 t (assuming two 100-km transport segments). This is based on an estimated 2×10^{-8} fatalities per shipment-km for accidents.

5.3.4 Summary of Nonradiological Health Impact Analysis

RSM recycle operations potentially present cancer fatality risks to workers and to the public from chemical exposures. Individual risks to both nuclear and industrial workers are likely to be less than the regulatory limit of 10^{-3}. Risks to the most exposed member of the public are estimated to be on the order of 10^{-4}. Fatality risks from accidents are substantially higher. Collective public risks from vehicle accidents in transporting RSM to a controlled melter and ingots to a commercial melter are estimated to be on the order of 10^{-2}. The risk of industrial accidents resulting in fatalities or serious injuries from the controlled and commercial melting processes combined is somewhat greater than eight incidents per 50,000 t of RSM.

5.4 ENVIRONMENTAL IMPACTS

Potential impacts to environmental resources that might be associated with recycling RSM include those to air quality, water quality, energy, and biota that might be affected by resource requirements, emissions, or waste generated by those operations. Environmental impacts from RSM recycle are difficult to quantify so a qualitative discussion is presented in Sections 5.4.1 through 5.4.5. No significant incremental environmental impacts are expected to result from the addition of RSM to the recycling industry. Resource savings from recycling metal of all types are considerable, particularly with regard to energy. Additional benefits from using steel scrap include reductions of 90% in raw material consumption (mainly coal) (Lund 1993). Section 5.4.6 discusses the potential for impacts on sensitive industrial technologies.

5.4.1 Air Quality

Recycling RSM involves three major activities that could generate emissions that would degrade air quality: decontamination, melting in a controlled smelter, and scrap remelting at a commercial mill. The presence of radioactivity and hazardous chemicals is likely to require efficient emission-control technology for exhaust air in decontamination and melting activities, so emissions from these activities are likely to have negligible impacts. Controls would likely be less stringent on emissions from commercial steel mills where the scrap would be remelted, and some air quality impacts are likely. However, in general, emissions from recycling are less than those from primary metal smelting because many impurities have previously been removed and less energy is generally required. A total reduction of 86% in air emissions for recycling has been estimated by Lund (1993).

5.4.2 Land Use/Disturbance

Impacts to land use from recycling RSM would be relatively minor. The main requirements are land for the development of facilities for decontamination and melting of RSM. About 10% of the inputs to controlled smelting would require disposal as LLW in the form of slag. Compared to steel production from ore and other raw materials, scrap recycling produces 97% less mining waste (Lund 1993).

5.4.3 Water Quality/Resources

Impacts to water and associated biota could potentially occur in the specific location of a processing facility for RSM. However, releases are assumed to be controlled to acceptable standards of the locale/country of the facility. Nitrates and phosphates associated with the initial decontamination reagents are not expected to increase the eutrophication of the receiving water, nor are the naturally occurring metals and other elements in the effluent expected to incrementally affect the receiving water, because precipitates would be separated from the effluent stream before discharge, and the flow ratio would further reduce incremental contaminant concentrations upon mixing. Thus, the release of decontamination effluents to the receiving stream is not expected to adversely impact related environmental resources. Over all the processes involved, other than decontamination, scrap recycling has been found to require 40% less water and to produce 76% less water pollution than producing steel from raw materials (Lund 1993).

5.4.4 Energy Requirements

Production of one ton of steel entirely from scrap metal requires approximately 10.5 GJ of energy (Steiner 1993). In metal production generally, most of the required energy inputs are applied in the refining stage, which can be avoided by using scrap. The energy savings from producing just one ton of steel from scrap rather than ore can meet the electricity needs of one U.S.A. household for one year. The relative energy savings from

using copper or aluminum scrap are even greater than for steel scrap. Copper production from scrap requires about half of the energy that primary production requires (Jolly et al. 1993). Manufacturing new aluminum cans from used ones requires 95% less energy than producing the cans from raw materials. Although some decontamination techniques such as electropolishing are relatively energy intensive, energy use for recycling RSM is still likely to be less than for replacement. These statements also generally apply to the commitment of energy in decontamination operations, except in the case of metal melting. The energy requirements for melting are high, and additional costs are associated with operation and maintenance for this facility compared with the other, common decontamination methods.

5.4.5 Industrial Technology Impacts

In a pilot study on the effects of radioactivity on scientific and technical equipment, the Japanese Atomic Energy Research Institute found that large-scale integrated circuits, high-sensitivity photographic film, and low-background radiation counters had the most potential for being deleteriously affected by residual radioactivity in metals (Kato et al. 1989). The possible impacts have been evaluated in more detail by S. Cohen & Associates, Inc. (1995). They concluded that there is a potential for impacts and that technology sensitivity to radiation may increase in the future, but lacked sufficient information to identify specific levels of activity in metals that might cause such impacts. Indeed, radiation-sensitive industries are coping with much higher radiation levels from ambient sources than would be introduced by RSM recycling

The computer industry could possibly be affected due to the effects of radiation on large-scale integrated circuits. The most important effect of radioactivity on such circuits is "soft error." Soft error is the temporary disruption of data caused by the movement of alpha particles through the circuit's memory array. The soft error rate is proportional to alpha flux and it increases as the integration density of large integrated circuits increases (Kato et al. 1989). As industry moves toward circuits with higher integration density, attention must be paid to the potential effects of residual radioactivity. The potential for soft error production due to naturally occurring uranium and thorium has been recognized for some time, so the industry seeks high-purity materials for inclusion in the circuits. The silicon chips are then encased in ceramic (which also may contain uranium or thorium impurities) or plastic material, which provides shielding from externally produced alpha and beta radiation. Modelling of alpha particle flux effects shows that a 1 Bq/g concentration in metals used in chip construction would meet industry standards (Yamamoto and Kato 1995).

High-sensitivity photographic film, such as that used for industrial or medical X-rays, is particularly reactive to the presence of radiation. The effect of this radiation exposure is to create "fog" which interferes with the clarity of the picture. Because of normal background radiation, fog intensifies linearly with film storage duration (Kato et al. 1989). Thus, the effectiveness of high-sensitivity medical and industrial film is reduced as it is exposed to more sources of radiation — residual or background.

Much of the world's steel supply has been contaminated as a result of the use of Co-60 in blast furnaces to assess furnace material deterioration and also the fallout from weapons testing. The resulting level of radioactivity in steel is estimated to be 10^{-5} to 10^{-4} Bq/g (Knoll 1979) which presents negligible risks to human health. However, this level of contamination does affect the minimum detection level of low-level, background radiation counters. As a result, only uncontaminated steel is used as the shield material for whole-body counters, which have low detection limits (Kato et al. 1989). Current practice in the U.S.A. is to use steel produced from low-activity raw materials for this purpose. Since this is already the practice, recycling RSM would not affect low-level radiation counters.

Deleterious effects of residual radioactivity and the costs involved in eliminating or controlling those effects should be considered when regulators determine acceptable levels of residual radioactivity in recycled materials. However, the need to minimize effects of residual radioactivity is not a new problem but one that sensitive industries have developed strategies to cope with. In addition, the radiation levels from recycled RSM are likely to be low relative to radiation from ambient and other manmade sources.

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6 IMPACTS OF RADIOACTIVE SCRAP METAL DISPOSAL AND REPLACEMENT

The alternative to recycling radioactive scrap metal (RSM) is to dispose of it — on the site of origin or in a designated low-level radioactive waste (LLW) disposal facility. Disposal would remove the RSM from the world stock of metals, major portions of which are normally recycled. Choosing not to use the RSM in production of new products would entail replacing this discarded metal with newly produced supplies. The mining and refining operations involved in producing the replacement stock would result in substantial impacts to human health and to air, land, and water resources. Section 6.1 discusses the health risks and issues associated with RSM disposal as LLW, including the costs and uncertainties regarding disposal-site capacity. Section 6.2 describes the impacts of the mining and refining associated with producing replacement metals. Section 6.3 examines the impacts of the production and consumption of coking coal in steel-making. Finally, Section 6.4 summarizes the various health and environmental impacts of not recycling RSM.

6.1 DISPOSAL OF RADIOACTIVE SCRAP METAL AS LOW-LEVEL WASTE

In this analysis, it is assumed that if RSM were not recycled, it would be transported to and disposed of in a licensed LLW disposal site. These activities would employ practices designed to limit worker and public radiation and chemical exposures to regulatory levels.

6.1.1 Disposal Process

Procedures for handling of RSM for collection and classification before disposal would likely be similar to those required before recycle or reuse. Therefore, impacts associated with these preliminary procedures would likely be similar for either the disposal or the recycle options for RSM and thus are not considered here. Some decontamination might also be required to prepare and package RSM for transportation to a LLW disposal site. This effort is likely to be less intensive for the disposal option than for recycling but would also be carried out by nuclear workers. It is assumed that worker exposures to radiation or chemicals would not exceed regulatory limits.

Disposal of RSM would involve the potential for three general types of health and environmental impacts. First are the health risks associated with the transport of the scrap to the disposal site. Second, health or environmental impacts could result from any release of contaminants from a disposal site. Finally, disposal requires the dedication of the disposal site for an indefinite period. Since disposal of RSM might involve the use of existing, licensed disposal facilities, issues associated with the use of such facilities for the disposal of RSM are also considered.

6.1.2 Health Risks of Disposal

6.1.2.1 Workers

Radiation doses to transportation workers would be similar to those discussed for recycle in Section 5.2.2.4. Shipping 50,000 t of RSM for a distance of 100 km in 20-t shipments would result in a maximum individual dose to the crew of 2×10^2 μSv/yr (lifetime cancer fatality risks of 1×10^{-5}).

Doses to workers involved in waste disposal activities would be limited by worker protection requirements. Therefore, individual maximum doses and risks to workers would be limited to an incremental lifetime cancer fatality risk of 10^{-3} per year of work. Collective worker doses at LLW disposal facilities would be small because of the small worker population exposed to radioactive materials at such facilities.

6.1.2.2 Public

Public risks from radiation exposure during RSM transportation for disposal would be similar to those discussed in Section 5.2.2.4. For the public, the collective dose is 2×10^{-2} person-Sv for transporting 50,000 t of RSM a distance of 100 km. Associated cancer fatality risks are 8×10^{-4}. Doses from disposal of 50,000 t of RSM at a LLW site are not specifically evaluated. However, since the LLW must meet the existing regulations for disposal (such as 10 CFR 61 [USNRC 1993]), health impacts from RSM disposal are likely to be similar to those for LLW disposal in general. Individual public doses must not exceed a regulatory limit of 1 mSv/yr (ICRP-60 [ICRP 1991], 10 CFR 20 [USNRC 1990]), which corresponds to a fatal cancer risk of 5×10^{-5}. ALARA procedures in disposal site design and LLW management are likely to render actual risks substantially lower. In the absence of an off-site release of contamination, a well tapped into the disposal site, or an intruder entering the disposal area, there would be no radiological impacts to the general public from the operation of a LLW disposal facility. The likelihood of such a release or intrusion is expected to be small. Furthermore, even if such an event did occur, the individual doses that might be received would likely be small, particularly if the LLW waste was disposed of below ground. Likely doses to the maximally exposed individual, an intruder, have been estimated to range from 35 to 200 μSv/yr (EG&G 1987).

National traffic fatality statistics have been used to estimate transportation accident fatalities, as discussed in Section 5.3.3.3. For disposal of 50,000 t of RSM, transportation accident fatality risks are approximately 5×10^{-3} per 100 km.

6.1.3 Land Use and Disposal Site Capacity

Most RSM generated in the U.S.A. will be Class A, B, or C LLW and therefore considered suitable for near-surface disposal (see 10 CFR 61.55 for definitions of Class A, B, and C wastes). Although projections are uncertain, very little waste of any type is produced

in the greater-than-Class C category, which in general is not acceptable for near-surface disposal (Oak Ridge National Laboratory [ORNL] 1992). Only about 550 m^3 of the more than 1.6×10^6 m^3 of LLW that could be produced by decommissioning of commercial reactors in the U.S.A. during the period 1992-2030 will be greater-than-Class C LLW (ORNL 1992).

Not all countries intend to place most LLW in near-surface disposal sites as is done in the U.S.A. For example, Germany, Switzerland, and the United Kingdom either have decided to use, or are considering the use of, geologic disposal for all LLW. Other countries in Europe (e.g., France and Spain) use or plan to use near-surface disposal only for LLW that has no significant quantities of isotopes with half-lives greater than 30 years. European countries are generally considering deep geologic disposal for all other LLW (Zaccai 1990).

6.1.3.1 Radioactive Scrap Metal Volumes Relative to Low-Level Waste Disposal Capacity

A partial inventory of RSM from various potential sources is provided in Section 3. RSM is not the only type of waste material produced by such sources. In general, other construction materials (such as concrete) will contribute much larger volumes of LLW. In addition, for environmental restoration activities (which will be necessary at many facilities associated with weapons production), contaminated soil will generally provide even larger volumes of materials that will require disposal. For example, at the Fernald Site in the U.S.A., which was formerly used to produce high-purity uranium, scrap metal (including scrap metal currently in storage) will contribute less than 2% of the total volume of wastes that will be associated with remedial activities (U.S. Department of Energy [DOE] 1993; ORNL 1992). At the Weldon Spring site, which also produced high-purity uranium metal, the contribution of metal will be about 6% of the total volume (MK-Ferguson Co. 1991). Metal will constitute about 10% of the total volume of the wastes associated with the decommissioning of the Oak Ridge Gaseous Diffusion Plant (Ebasco 1991; ORNL 1992). Concrete is expected to dominate the volume of waste materials generated by the decommissioning of nuclear power plants. Depending on how RSM disposal is managed as a part of a much larger overall disposal problem, the potential for impacts of RSM disposal could vary substantially.

The disposal volume of RSM generated by dismantling of power reactors is sensitive to the period of time between nuclear power plant shutdown and dismantling, as is illustrated by the projections presented in Section 3.3.2. Because of radioactive decay, delays in dismantlement of 50 to 100 years after decommissioning would result in major reductions in the quantity of radioactive scrap metal. Therefore, decisions concerning the schedule for dismantling will have a major impact on the volume of radioactive scrap that might require disposal. This issue is important for both on-site and off-site disposal. For off-site disposal, the volume will also determine transportation costs, which can be significant for cases in which wastes must be transported long distances.

All commercial LLW disposal sites in the U.S.A. combined were projected to receive about 33,000 m^3 of LLW in 1993 (ORNL 1992). The annual disposal volume for commercial

LLW in the U.S.A. has decreased substantially during the last decade because of increased disposal costs, waste compaction, and source reduction. The annual volume of LLW requiring disposal in the U.S.A. is projected to continue to decrease and to reach about 21,000 m^3 in the year 2024 (ORNL 1992).

Table 3.4 (Section 3) provides estimates of the quantities of scrap iron and mild steel expected from U.S.A. power reactors 50 years after start-up. In the peak year of this scrap flow (2024), about 36,300 t of activated material, about 76,800 t of material with removable surface contamination, and about 79,700 t of nonradioactive material would be produced. These quantities correspond to volumes of roughly 6,500, 14,000, and 14,500 m^3, respectively, assuming metal with about 30% void space and a metal density of 8 t/m^3. The volume of activated material alone would be equivalent to about 30% of the expected annual volume of commercial LLW in the U.S.A. in the year 2024; the volume of activated material plus material with surface contamination would be equivalent to about 100% of the expected annual LLW volume in the year 2024; and the volume of all the metal scrap would be equivalent to about 160% of expected annual LLW volume.

6.1.3.2 Low-Level Waste Disposal Charges

Only two commercial LLW sites are currently accepting new wastes in the U.S.A. — Barnwell, in South Carolina, and Richland, in the State of Washington. The unit cost of disposal for LLW is high and is increasing rapidly. For the Barnwell site, the basic disposal charge,[1] as of January 1, 1993, is $\$2,083/m^3$ (about \$330/t for steel, assuming 30% void space), plus a 2.4% county tax (Chem-Nuclear Systems 1993). Various surcharges, including one for activity, also apply. The basic disposal charge has increased from $\$466/m^3$ (about \$75/t for steel) in 1983 (in 1983 U.S. dollars), an average annual rate of increase of about 16%. Average annual inflation in the U.S.A. over the same period was about 4%. Some reduction in disposal charges may be possible for large-volume customers; however, basic costs will still remain high. In addition to the basic charge, a surtax of $\$1,200/m^3$ (about \$190/t for steel) also applies to wastes originating from states outside South Carolina, but inside the Southeast Compact.[2] For states outside the Southeast Compact, a surtax of $\$7,766/m^3$ (about \$1,240/t for steel) applies. Barnwell is scheduled to close for generators outside the Southeast Compact in July 1994. It will close in January 1996 for generators in the Southeast Compact.

The Washington site is already closed to most outside wastes. The basic disposal cost for that site (1993 U.S. dollars) is about $\$1,730/m^3$ (about \$277/t for steel) (U.S. Ecology 1993). The actual disposal cost for the Washington site depends on the radiation rate at the surface of the waste container. Various surcharges also apply, including a surcharge for activity. Although new LLW disposal facilities are anticipated to become available, it is

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[1] All monetary values are given in U.S.A. dollars (\$) unless otherwise noted.

[2] The Southeast Compact is a group of eight southern U.S.A. states that joined to manage their low-level radioactive waste, pursuant to the Low-Level Radioactive Waste Policy Act of 1980, which authorizes approved state compacts to exclude waste from out-of-compact states.

expected that disposal costs in the U.S.A. will continue to increase and that access to LLW disposal sites will continue to be limited on the basis of the geographic location of the waste generator. Basic disposal costs at new facilities are expected to exceed $\$10,600/m^3$ (about \$1,700/t for steel) (Gardner 1993).

Another facility in the U.S.A. — the Envirocare site in Utah — accepts low-activity wastes that do not require management at LLW sites but that still pose potential environmental concerns. A preliminary cost of about $\$200/m^3$ (which corresponds to about \$32/t for steel) was estimated in 1992 for disposal at Envirocare of about 500,000 m^3 of waste from the Weldon Spring site (DOE 1992b). For smaller volumes (but above 1,400 m^3/yr), costs for the facility have historically been in the range of about $\$900\text{-}1,600/m^3$ (about \$140-260/t for steel) (Gardner 1993).

In Europe, actual or anticipated costs for LLW disposal vary considerably but typically are a function primarily of site capacity and depth of disposal (Zaccai 1990). Costs for deep disposal are about two to three times those for shallow disposal for sites with similar capacities. Facilities for disposal of LLW currently are available or are under construction in a number of European countries, but, in general, new facilities will be required to accommodate wastes generated during the decommissioning of nuclear facilities (Nuclear Energy Agency 1991).

Anticipated costs (1992) for disposal in Belgium are BF $205,000/m^3$ (about BF 33,000/t for steel) for LLW with no significant quantities of isotopes with half-lives greater than 30 years and BF $325,000/m^3$ (about BF 52,000/t for steel) for geologic disposal of other waste (Teunckens 1993). For France, the costs for off-site shallow land disposal for LLW were estimated in 1989 to be FF $5,000/m^3$ (about FF 800/t for steel) for a decommissioning project (Nuclear Energy Agency 1991). Estimated costs for the disposal of decommissioning wastes (which may not all be LLW) in several European countries are as follows (in 1990 U.S.A. dollars/m^3): Finland, \$1,400-\$1,600; Spain, \$2,000; Switzerland, \$1,000 (Nuclear Energy Agency 1991). (For steel with about 30% void space, these costs correspond to a cost per ton of about \$220-\$260, \$320, and \$160, respectively.) In Canada, similar disposal costs for LLW were estimated to be (in 1990 U.S.A. dollars) $\$600\text{-}\$4,000/m^3$ (about \$100-640/t for steel) (Nuclear Energy Agency 1991). In the United Kingdom, current (1993/1994) provisional costs for LLW disposal at the Drigg site are £632/m^3 (about £100/t for steel) for surface disposal in engineered concrete vaults (Cross 1993). Because of a reduction in projected disposal volumes, the provisional cost for 1994/1995 (in 1993 money values) is £1,043/m^3 (about £170/t for steel). Charges for level of activity are also applied to wastes disposed of at Drigg. The United Kingdom has decided to abandon near-surface disposal of LLW at future sites.

Politically, LLW disposal is a significant issue in the U.S.A. in other countries. Public concern has resulted in a situation in which only two commercial sites in the U.S.A. are currently accepting LLW. One of these sites is scheduled to close soon, and restrictions or cost penalties apply to LLW on the basis of the geographic origin of the waste. Political decisions are likely to govern available LLW capacity and access in the U.S.A. during the

period of interest for this study. However, other countries, in particular France and Sweden, have been successful in siting LLW disposal facilities (McCabe 1993).

Because RSM will typically contribute only a small fraction of the volume of wastes that will be generated by many of the facilities that are sources of RSM, the disposal of such scrap metal will generally result in long-term land use impacts or costs that are only incremental and likely negligible for those cases in which the various types of wastes are placed together in the same disposal facility. This situation would be particularly true in the case of a new facility dedicated to the disposal of wastes from a specific site. However, if RSM is segregated before disposal, managed separately, and shipped for disposal to an off-site facility, as might be the case for wastes generated by dismantling of commercial nuclear power plants, then the disposal of the scrap metal could place potentially significant demands on limited LLW disposal capacity. The significance of those demands would depend on the period of time allowed between facility shutdown and dismantlement. Unit costs for off-site disposal will be high, and, at least in the U.S.A., availability of and access to LLW disposal sites will be determined politically.

6.2 REPLACEMENT OF RADIOACTIVE SCRAP METAL

RSM replacement requires both metal ore mining and refining and coke production from coal for manufacture of steel. Health and environonmental impacts of these activities are described below, and effects are estimated for replacing 50,000 t of steel.

6.2.1 Metal Mining and Refining Processes

If RSM is not recycled, the discarded metal would be replaced through mining and processing ore. Because mining and refining often occur at the same location and with overlapping impacts, the impacts of mining and primary processing are discussed together. Steel production uses a significant amount of scrap in primary smelting — approximately 25-30% of the charge in a basic oxygen furnace. The impact estimates for steel production presented below are adjusted for scrap use, indicating the impacts attributable to the virgin ore input per ton of steel produced.

The discussion presented here is limited to direct impacts of processing metals from ores. Impacts from the production and use of the fuel necessary to refine the ores or from the production and use of fluxes that must be added in the smelting processes are excluded. However, the impacts associated with coke production and consumption in steel-making are considered in Section 6.3.

6.2.1.1 Mining

The international distribution of the impacts of replacing RSM depends on the distribution of mining and refining operations. Annual production data for the 10 major producing countries are presented in Table 6.1 for iron and crude steel, and in Table 6.2 for

TABLE 6.1 Top 10 Countries' Annual Iron Ore and Crude Steel Production, 1980 and 1990[a,b,c]

	Production[d] (10^6 t)			
	Iron		Steel	
Country	1980	1990	1980	1990
Australia	95.5	110.0		
Brazil	114.7	150.0	15.3	20.6
Canada	48.8	36.4		
China	68.1	118.0	37.1	66.0
Former Soviet Union	244.7	236.0	147.9	154.0
France			23.2	19.0
Germany[e]			51.1	44.0
Italy			26.5	25.4
India	41.9	52.0		
Japan			111.4	110.3
Korea, Republic			8.6	23.1
South Africa	26.3	30.3		
Sweden	27.2	19.9		
United Kingdom			11.3	17.9
U.S.A.	70.7	59.0	101.5	89.7
Venezuela	16.1	20.4		
Total — 10 Countries	721.7	754.0	744.5	832.1
Total — World	902.4	890.9	860.6	864.4

[a] Iron ore production is expressed in gross weight of ore mined (marketable product). Iron ore production refers to iron ore, iron ore concentrates, and iron ore agglomerates (sinter and pellets).

[b] Crude steel production is defined as the total of usable ingots, continuously cast semifinished products, and liquid steel for castings. The United Nations' definition of crude steel is the equivalent of the term "raw steel" as used by the U.S.A. Raw steel is composed of about 30% scrap, with pig iron made from virgin ore accounting for the rest.

[c] Totals may not add exactly because of rounding.

[d] A blank indicates that a particular country in not one of the 10 leading producers of that commodity.

[e] Data are for both Federal Republic of Germany and German Democratic Republic.

Source: World Resources Institute (1992).

TABLE 6.2 Top 10 Countries' Annual Production of Copper, Aluminum, Lead, and Nickel, 1990[a]

Copper[b]		Aluminum[c]		Lead[d]		Nickel[e]	
Country	Production (10^3 t)	Country	Production (10^3 t)	Country	Production (10^3 t)	Country	Production (10^3t)
Chile	1,603	Australia	40,697	Australia	563	Former Soviet Union	259
U.S.A.	1587	Guinea	16,500	U.S.A.	495	Canada	202
Canada	780	Jamaica	10,921	Former Soviet Union	450	New Caledonia	88
Former Soviet Union	600	Brazil	8,750	China	315	Australia	70
Zambia	445	India	5,000	Canada	236	Indonesia	58
Poland	380	Former Soviet Union	4,200	Peru	189	Cuba	41
China	375	China	4,000	Mexico	180	South Africa	36
Zaire	370	Suriname	3,267	Korea, DPR	120	Dominican Republic	33
Peru	334	Former Yugoslavia	2,952	Sweden	90	Botswana	25
Australia	316	Greece	2,700	Former Yugoslavia	73	China	25
Total - 10 Countries	6,790		98,987		2,711		837
Total - World	8,814		109,118		3,367		937

[a] Totals may not add exactly because of rounding.

[b] The annual production data represent the metal content of the ore mined for copper.

[c] Aluminum (bauxite) is expressed in gross weight of ore mined (marketable product).

[d] The annual production data represent the metal content of the ore mined for lead.

[e] The annual production data represent the metal content of the ore mined for nickel.

Source: World Resources Institute (1992).

copper, aluminum, lead, and nickel. These countries would be most likely to experience a majority of the impacts of RSM replacement.

In the mining of ores, the choice between surface or subsurface mining techniques for a particular site depends on such factors as the size, structure, and accessibility of the ore deposit. That choice makes a significant difference in the impacts of the mining operation. In the U.S.A., surface mining of minerals produced 11 times as much waste per ton of ore as underground mining did in 1988 and 8 times as much as waste in 1993 (Young 1992b). However, although subsurface mining generates less waste, it is more dangerous and expensive than surface mining.

6.2.1.2 Refining/Smelting

Most of the pig iron produced from a blast furnace is refined into steel; small amounts are made into other forms of iron, such as cast iron (DOE 1992a). Technological advances in blast furnace operations during the 1970-1990 period decreased the amount of coke required to produce a ton of pig iron by about 20%, from 0.6 t in 1970 to 0.5 t in 1990. The smaller amounts of coke consumed in U.S.A. steelmaking during the 1970-1990 period also reflect the greater use of the electric arc furnace (EAF), although to a lesser extent than the technological advances experienced in blast-furnace operations. Nevertheless, the share of total raw steel output from EAFs more than doubled from 15% in 1970 to an average of 37% since 1986, as more scrap iron and steel was recycled into steelmaking. The EAF produces steel from a charge composed of 99% scrap and 1% iron pellets. Currently, the EAF has become more productive and versatile because technological improvements are reducing the time required to produce steel (American Iron and Steel Institute undated; DOE 1992a).

Coal consumption by the iron and steel industry can be expected to move towards the use of lower-quality coking coal in blends with high-quality coking coal, as well as the introduction and implementation of new technologies such as pulverized coal injection (PCI). This technique allows direct injection of limited amounts of coal into the blast furnace, in conjunction with coke and sintered iron ore. Direct injection of coal is more economical because 1 t of pulverized coal, when injected, can replace 1.4 t of coking coal; and noncoking coals can be used in injection (International Energy Agency 1992).

6.2.2 Health Risks of Metal Mining and Refining

Human health effects are associated with both mining and refining of metals. These effects include worker injuries, worker illnesses, and public illnesses due to exposure to toxic elements. Because of the nature of the available data, the health effects of mining and ore concentrating activities and of refining activities are presented separately.

6.2.2.1 Workers

Radiation Exposures

Underground miners face the hazards of exposure to toxic gases and radon, as well as to low levels of other radionuclides, depending on the geology of the mine site. Copper and bauxite ores, for example, often occur in strata containing above-average concentrations of uranium, thorium, and their decay products. While radiation exposure poses less of a threat to aboveground miners, both underground miners and workers involved in ore-enhancing procedures can have significant exposures to radiation if proper safety and ventilation measures are not employed (U.S. Environmental Protection Agency [USEPA] 1978).

Radon concentrations of 280 Bq/m^3 were measured in the air in an underground iron mine in the U.S.A. in 1978 and in a similar mine in the Federal Republic of Germany in 1984. Studies of underground copper mines have found radon levels such as 160 Bq/m^3 in the U.S.A. in 1978, 1,200 Bq/m^3 in India in 1987, and a range of 9,000-20,000 Bq/m^3 in China from 1975 through 1978. Occupational exposures attributable to radiation in nonuranium mines have decreased with time because monitoring has led to a reduction of high-exposure situations. On the basis of these findings, the United Nations (1993) estimates annual radiation exposure of nonuranium miners at 0.1 to 200 mSv. The associated lifetime cancer fatality risk for miners due to these exposures is in the range of 5×10^{-5} to 1×10^{-2}. The ower end of the range may be more representative of current conditions especially in more developed countries. The resulting collective dose to miners from replacing 50,000 t of RSM is estimated to be about 4×10^{-3} person-Sv/yr, assuming an average dose of 10 mSv/yr.

Mining Accidents

Mining is a high-risk occupation. In 1990, the annual worker fatality rate in iron mining in the U.S.A. was 3×10^{-4} and the occupational injury rate was 2.8×10^{-2} (U.S. Department of Labor 1991). An "occupational injury" is defined as an injury for which medical treatment is administered, or which results in death or loss of consciousness, restriction of work or motion, inability to perform all job duties on any day after an injury, lost workdays, temporary assignment to other duties, transfer to another job, or termination of employment. In 1990, copper miners in the U.S.A. suffered 5 fatal and 260 occupational injuries. Refined copper production in that year totaled 1,566,876 t; thus, 3.1×10^{-6} fatalities and 1.7×10^{-4} injuries occurred per ton of primary copper produced ($260 \div 1{,}566{,}876$). Also in 1990, iron ore miners had 6 fatalities and 345 occupational injuries (U.S. Department of Labor 1991) in mining the ore to produce 35,695,000 t of steel (Kuck 1993). Adjusting for scrap content, the fatality rate was 2×10^{-7} and the injury rate among miners was 1.3×10^{-5} per ton of steel produced ($345 \div [35{,}695{,}000 \times 0.75]$). Since the U.S.A. no longer mines metal-grade bauxite ore, similar statistics were not available for aluminum production.

The severity of the injuries is indicated by the average number of lost workdays per injury. In 1990, an average of 88 workdays was lost for each mining injury (all types of

mining combined). The copper mining average was 159 lost workdays and the iron ore mining average was 56 days, representing an average of 0.075 workday lost per ton of copper and 0.002 per ton of steel during mining operations (U.S. Department of Labor 1991).

Additional areas of particular health and safety concern in mines are excessive noise and inadequate ventilation of underground mines. Excessive noise from use of explosives at mines and use of heavy machinery at mines and refineries can cause hearing impairment. Poor ventilation can result in explosions and fires and can increase the risk of respiratory illnesses or suffocation.

Refining Accidents

According to the U.S. Department of Labor (1989), the annual rate of work-related fatalities and serious injuries in blast furnaces and steel mills in 1987 in the U.S.A. was 5.7×10^{-2}, compared with the entire private-sector average of 3.8×10^{-2}. The number of lost workdays for blast furnace and steel mill workers in 1987 was 155.6 per 100 workers, more than twice the private sector average of 69.9 per 100 people. On a production-unit basis, these numbers represent 1.4×10^{-4} fatalities or injuries and 4×10^{-3} lost workdays from refining activities for each ton of steel produced. Replacing 50,000 t of RSM would thus incur a risk of 7 worker fatalities or serious injuries.

The 1987 rate of work-related fatalities and serious injuries in of refining and smelting primary nonferrous metals in the U.S.A. was 7.7×10^{-2}. The values for specific metals included 6.9×10^{-2} for primary copper, 0.9×10^{-2} for primary aluminum, and 1.1×10^{-1} for primary lead. These rates are among the highest for all occupations, representing 3.7×10^{-4} fatalities and injuries for each ton of copper and 5.7×10^{-4} for each ton of aluminum. The number of lost workdays per 100 full-time primary nonferrous workers in 1987 was 148.8. The number of lost workdays per 100 workers in primary copper, primary aluminum, and primary lead were, respectively, 186.4, 156.7, and 296.8 — again, among the highest for all occupations. These rates represent 0.011 lost workdays per ton of aluminum produced and 0.010 lost workdays per ton of copper (U.S. Department of Labor 1989).

6.2.2.2 Public

Chemical Exposures from Mining

The health effects to the general public from mining stem primarily from trace elements from acid drainage or from dust blown from overburden and tailings piles. The most common exposure pathways to the general public are ingestion of contaminants from drinking water sources or the food chain and inhalation of suspended particulates. The range of possible effects of trace metal intake includes sterility, hypertension, birth defects, stunted growth, damage to the central nervous system, anemia and other hematological abnormalities, neurological damage, bone damage, urinary and hepatic disorders, cancer, and

death (Brookins 1990). A listing of typical contaminants and associated health effects is provided in Appendix E.

Mine Accidents

Another hazard to the public is the danger of falling into an abandoned mine. The western U.S.A. alone has about 500,000 abandoned mines, and little funding is currently available to properly seal them. The number of deaths and injuries created by this hazard is not large, but it will continue to be a problem (Schneider 1993).

Transportation Accidents

Bulk transport of ore by train or barge would result in accident fatality risks for the public. Assuming replacement of 50,000 t of RSM and a 100-km transport distance, the fatality risk incurred would be 3×10^{-3} to 9×10^{-2}. This range is based on data for coal transport (DOE 1988).

Radiation Exposures from Refining

In the U.S.A., the National Council on Radiation Protection and Measurements (NCRP 1987) conducted a study of the annual effective dose equivalent from radiation exposure to nearby individuals for selected primary metal processing plants. Exposure levels were higher for nonferrous than for ferrous metals. Listing the organ with the highest dose, aluminum reduction plants expose about 3,400 local residents' kidneys to 12 μSv, copper smelters expose 4,800 individuals' lungs to 2 μSv, and lead smelters expose 14,000 individuals' lungs to 50 μSv annually. Other public health effects potentially result from exposure to trace metals and other pollutants that are released into the air, water, and ground from waste piles or through other refining processes.

Chemical Exposures from Smelting

Replacing RSM from ores would involve production of pig iron in a blast furnace operation, followed by carbon reduction in a smelter to produce steel. These activities produce stack emissions of hazardous chemicals released to the atmosphere, and potential releases to air and water from slag and emission control system dust/sludge. On the basis of conservative assumptions, the associated public health risks, which are detailed in Section 5.3.3.2, are about 2×10^{-4} fatal cancers from production of 50,000 t of steel.

6.2.3 Environmental Impacts of Metal Mining and Refining

Steel production causes environmental impacts directly by changing land surfaces and water drainage patterns, and it also causes impacts through release of hazardous

substances to air, land, and water, damaging resource quality. These impacts, as well as energy requirements for steel production activities, are discussed in this section.

6.2.3.1 Air Impacts

Most air emissions generated in the production of metals from virgin materials are from the ore-enhancement and smelting processes. However, some air emissions from mining also present a hazard to miners and to neighboring communities. Traffic from major mining and refining operations may also affect air quality in the vicinity, even though care is often taken to reduce dust production by sprinkling water on roads and other disturbed sites. This dust can be harmful to workers and residents near an operation, especially if it contains traces of toxic elements. Trace elements, gaseous emissions, and radiation are the major types of contaminants released to the atmosphere during the refining and smelting stages of metals production.

Trace metals released into the atmosphere from tailings piles at mines can be hazardous to the public if they enter the food chain and are ingested, especially by children. Hwang (1990) indicates that varying amounts of arsenic, cadmium, chromium, copper, lead, zinc, beryllium, silver, selenium, barium, molybdenum, manganese, nickel, iron, and silica can be blown as particulate matter from copper mine tailings piles, depending on the soil composition at the mine site. Amounts of trace elements released from smelting and refining processes are shown in Table 6.3. The low end of the range of emission estimates represents the more efficient combinations of production technology, pollution control, and raw material inputs with the lowest concentrations of contaminants. The high end represents the least efficient processes and highest contaminant concentrations. These estimates may under-represent the global emissions rate because pollution-control requirements in developing countries can be less stringent than those in Europe and North America (Nriagu and Davidson 1986).

In addition to the hazards of trace element releases, sulfur dioxide (SO_2) emissions are a major concern because of their role in causing "acid rain." Worldwide, smelting of copper and other nonferrous metals results in the release of about 6×10^6 t of SO_2 into the atmosphere each year, which is about 8% of global SO_2 emissions (Young 1992b). Smelting and converting a typical copper concentrate produces more than 0.5 t of SO_2 per ton of concentrate (Peacey 1992), which must be controlled to meet local emissions standards. With the installation of atmospheric emission control equipment in recent years, SO_2 emissions in the U.S.A. have been controlled by more than 99% (Jolly 1993). Use of emissions control equipment is becoming standard practice throughout the world, but such equipment is expensive and not always required by law.

Iron and steel production released 54,400 t of nitrogen oxides (NO_x), 144,400 t of SO_2, and 37,700 t of volatile organic compounds to the atmosphere in the U.S.A. in 1988 (Kohout et al. 1990). These values equated to about 0.270 kg of NO_x, 0.717 kg of SO_2, and 0.187 kg of volatile organic compounds for each ton of steel produced (using the same

TABLE 6.3 Emissions of Trace Metals to the Atmosphere and Water from Metal Production Operations

Element Released	Emissions from Pyrometallurgical Metal Production[a] (g/t)			Liquid Effluents of Smelting and Refining[b] (ng/L)	
	All Nonferrous Mining	Steel and Iron Manufacturing[c]	Copper and Nickel Production	Iron and Steel[c]	Nonferrous Metals[d]
Antimony	1-10	0.005-0.1	50-200	—[e]	0.04-3.8
Arsenic	5-10	0.5-3.5	1,000-1,500	—	0.5-6.4
Cadmium	0.1-0.5	0.04-0.4	200-400	—	0.004-1.8
Chromium	—	4-40	—	—	1.5-10
Copper	20-100	0.2-4.0	1,700-3,600	—	1.2-8.5
Indium	—	—	1-4	—	—
Lead	500-1,000	1.5-20	1,300-2,600	0.2-0.4	0.5-3.0
Manganese	50-100	1.5-40.0	100-500	2.0-5.2	1.0-7.5
Mercury	—	—	—	—	0.001-0.002
Molybdenum	—	—	—	—	0.003-0.2
Nickel	~100	0.05-10.0	900	—	1-12
Selenium	1.0-2.5	0.001-0.003	50-150	—	1.5-10
Thallium	—	—	—	—	—
Tin	—	—	50-200	—	—
Vanadium	—	0.1-2.0	5-10	—	0-0.6
Zinc	50-100	10-45	500-1,000	0.8-3.5	1-10

[a] Based on the review of emission studies in Western Europe, the U.S.A., Canada, and the Soviet Union in 1983. The range is determined by (1) the concentration of the trace elements in the raw material, (2) the production technology employed in the emitting industry, and (3) the type and efficiency of pollution control.

[b] Based on a critical survey of the extensive databases on the trace metal concentrations in industrial and municipal solid wastes and aqueous effluents. Data are mostly from the 1970s and 1980s.

[c] Data include blast, basic oxygen, and electric arc furnace information.

[d] Data include primary and secondary smelter information.

[e] Negligible.

Source: Nriagu and Pacyna (1988).

production information that was used by Kohout et al. [1990]). A total of 2,400 t of NO_x, 65,300 t of SO_2, and 400 t of volatile organic compounds were released to the atmosphere by primary aluminum smelting; the equivalent of 0.608 kg of NO_x, 16.5 kg of SO_2, and 0.101 kg of volatile organic compounds per ton of primary aluminum. Primary copper smelting in the U.S.A. released 1,400 t of NO_x, 297,000 t of SO_2, and a negligible amount of volatile organic compounds to the atmosphere (Kohout et al. 1990), or 0.967 kg of NO_x and 205 kg of SO_2 emissions per ton of primary copper, a much lower value for SO_2 production than given above by Peacey. The difference here is due to atmospheric controls in smelters. Primary lead and zinc smelters released 1,700 t of NO_x and 119,200 t of SO_2 to the atmosphere.

Fluoride particle control is the main atmospheric emission problem in the production of primary aluminum. Most primary smelters around the world have installed systems to collect and recycle the fluoride material to the production cells. These systems are typically at least 97% effective. About 0.5 to 1 kg of fluoride is produced per ton of aluminum. The improved equipment now used at many aluminum smelters has considerably reduced the environmental damage (particularly to trees and other vegetation) previously associated with fluoride emissions (Carwile 1993). Other potential air pollutants include SO_2 from the boiler house and lime, bauxite, and alumina dust from the refineries. Absorbent filters and electrostatic precipitators can be effective in controlling these emissions.

Particulate emissions from steel manufacturing are a threat to the air quality around steel mills. At integrated steel mills, where steel is made from about 75% iron ore, 50 kg of dust is produced per ton of steel (Nriagu and Davidson 1986). For blast furnaces equipped with 99%-efficient control devices, 580 g of particulate emissions are produced per ton of pig iron. Zinc (0.3 to 33 g/t), lead (0.1 to 8 g/t), and manganese (2.9 to 5.8 g/t) are among the trace elements found in this dust.

Steiner (1976) reports an average range of 7 to 30 kg of "dust and fume" generated by a basic oxygen furnace per ton of steel produced at the next stage in steel production. Table 6.4 lists the chemical composition of this dust by percentage of total mass for a noncombusted gas system typical of the majority of basic oxygen furnaces in the world. Iron is the predominant component, constituting 66.7% of this dust, and iron oxide is second at 21.4%.

TABLE 6.4 Components as a Percentage of Total Mass of Particulate Emissions from Basic Oxygen Noncombusted Gas Systems

Component	Percentage
Fe_2O_3	4.0
FeO	21.4
Iron	66.7
SiO_2	1.3
CaO	3.7
MgO	trace
P_2O_5	0.4

Source: Steiner (1976).

Radon gas poses a potential threat to workers in underground mining operations. Proper ventilation of mines alleviates this problem for workers, and occupational exposures attributable to

radiation in nonuranium mines have been decreasing with time. However, radon vented from underground mines can then be released to the atmosphere and possibly expose the public to this radioactive gas. Annual atmospheric radon releases of 2,600 GBq were reported for one iron mine in the U.S.A. (United Nations 1988).

In the last two decades, studies of aluminum facilities in the U.S.A. have found emissions of radon to be much higher than those of other naturally occurring radionuclides. Among the particulates, Pb-210 and Po-210 were found to be the most important components of the releases, because of the high temperatures of the kilns and reduction cells (United Nations 1988). Estimates of radionuclides per gram of particulate emissions for alumina kilns and bauxite residue kilns at an alumina plant are given in Table 6.5. The values do not represent the total activity released because the high temperature of the kiln causes a large fraction of the radionuclides to be volatilized (USEPA 1984a).

TABLE 6.5 Radionuclides in Particulate Emissions from Reference Copper and Alumina Plants

	Concentrations (Bq/g)		
Radionuclide	Alumina Kilns	Bauxite Residue Kilns	Copper Smelter
U-238	0.002	–[a]	0.026
U-234	0.002	–	0.026
Ra-226	0.001	–	0.001
Rn-222	–	0.748	–
Pb-210	–	0.013	0.043
Po-210	–	0.011	0.020
Th-228	–	–	0.001
Th-230	–	–	0.001
Th-232	–	–	0.001

[a] Negligible.

Source: USEPA (1984a).

6.2.3.2 Land Use Impacts

The impacts of metal mining and refining on land resources can be generally divided into two major categories: impacts that result from changes in the physical structure of the land and impacts that result from release of toxic materials.

A major factor relative to the physical impacts from mining is the total amount of land used by mining operations. A larger iron-ore-mining operation, for example, requires from 1,200 to 4,000 ha of land for mining, waste dumps, plant operations, and tailings disposal (Klinger 1985). Another author estimated on the basis of 1980 data for worldwide land use that each year 500,000 ha of land is directly disturbed by nonfuel mining, including mines, waste disposal sites, and areas of subsidence over underground mines (Young 1992b). This estimate, however, excludes both previously mined land that remains ruined and the land used in refining the mined ores.

Impacts on land from surface and subsurface mining differ greatly. In 1988, overburden accounted for more than a third of the 3.3×10^9 t of material handled at nonfuel surface mines (Young 1992a). Although subsurface mining produces less wastes, it poses the problem of subjecting the land above an underground mine to potential subsidence or collapse, which can seriously affect any land use or structures above the mine and cause financial losses.

Some lands, such as deserts and tundra, are particularly sensitive to mining impacts. Some arid lands are covered by a thin layer of pebbles over fine silt several centimeters thick. The layer of pebbles, called desert pavement, protects the finer material from wind erosion. When the pavement layer is disturbed by road building or other activity, the fine silts may be eroded, thus impairing physical, chemical, and biological properties of the soil in the immediate environment and scarring the land for many years. In other fragile areas, such as marshlands and the northern tundra, the presence of wet soils rich in organic materials makes the land sensitive to even light traffic (Miller 1991). Mining in tropical rain forests is likely to have substantial impacts on the ecosystem and native peoples that are dependent upon it. As the demand for metals increases, exploration and mining will likely increase in these previously avoided sensitive areas.

Mining wastes originate from two main sources in the mining and processing stages: (1) "overburden" or development waste rock, which is the material that must be removed to expose an ore body or develop a mine; and (2) "tailings," which are ore residuals that result from beneficiation of ores. (Beneficiation is the process of improving ore grade or concentration before smelting and includes such processes as floatation and drying.) Tailings comprise produce large quantities of waste because the desired metal generally is only a small percentage of the ore removed. Specialists at the U.S. Bureau of Mines have determined the worldwide average grades for certain metals as follows: 0.40 for iron ore, 0.23 for bauxite, 0.0091 for copper, and 0.025 for lead and nickel (Rogich 1992). Thus, for example, one ton of copper ore contains only 0.91% copper metal and 99.09% "waste" material. Because of these low natural concentrations of the metal, no practical means exist for reducing the volume of wastes generated.

Mining and milling operations have a major impact because of the large volume of wastes they generate. These wastes are often piled many meters high and cover extensive land areas. The piles of waste degrade the natural environment and create serious physical hazards, such as rock and mud slides that can threaten life and property within the vicinity (Koren 1991). In the U.S.A. alone, the mining industry generates up to 2×10^9 t/yr of solid waste and accounts for about 40% of the total solid waste generated annually by all sources in the country (Hoye and Hubbard 1989). Although about 80 types of mineral industries generate substantial wastes, 8 are responsible for about 80% of the total. The copper industry is the largest contributor, followed by the iron and steel, bituminous coal, phosphate rock, lead, zinc, alumina, and anthracite industries (Koren 1991). In the U.S.A. alone, copper mining and milling wastes are accumulating at the rate of about 500×10^6 t/yr, the greatest mass of solid wastes produced by any industry (Fitzgerald 1976).

The accumulations of overburden and tailings from mining operations inevitably change the original topography of the land, especially since much of the land is never reclaimed. Although some countries have laws requiring land reclamation, even in the U.S.A., which has enacted relatively strict laws, an average of less than 50% of mined land has been reclaimed. In 1980, for example, only 4.2% of the lands used by the iron ore mining industry and only 2.9% of the lands used by the copper mining industry were reclaimed there (Johnson and Paone 1982).

In addition to the physical disruption of land that mining and refining cause, the wastes also pose toxicity hazards. The following trace elements have been found to be common in copper mine tailings in concentrations ranging from a few parts per million: arsenic, cadmium, chromium, copper, lead, zinc, beryllium, and silica (Hwang 1990). Trace elements found in lead tailings may include arsenic, cadmium, chromium, copper, lead, zinc, beryllium, silica, silver, selenium, mercury, molybdenum, manganese, and iron (Hwang 1990). The presence of these trace elements poses substantial environmental and human health hazard associated with the dispersion or use of tailings from these and other mining operations. A summary of health hazards associated with some of these trace elements is provided in Appendix E.

Mining and refining wastes also have radioactive constituents. Copper ore often occurs in conjunction with elevated concentrations of uranium, thorium, and other radioactive elements. As a result, the potential impact of the large quantities of wastes from copper production involves hazards from the radioactivity released to soils and the food chain (Fitzgerald 1976). Radionuclide activity levels for materials involved in the production of alumina from bauxite ores are listed in Table 6.6. Radionuclide concentrations, for Ra-226, Th-232, and K-40 in steel slag, copper slag, nickel slag, and iron-chromium-carbon slag (from the production of stainless steel) are listed in Table 6.7.

In the metals refining process, slag from smelters and furnaces is often a waste product as well. In steel production, blast furnaces produce about 350 kg of slag for each ton of pig iron, resulting in about 265 kg of slag per ton of steel (if steel is produced from about 75% pig iron and 25% scrap). Basic oxygen furnaces produce 75-120 kg of slag per ton of

TABLE 6.6 Activity of Naturally Occurring Radionuclides in Alumina Plant Process Samples

	Concentrations (Bq/g)	
Substance	U-238	Th-232
Bauxite ore	0.250	0.200
Alumina kiln feed	0.002	0.002
Alumina product	0.010	0.07
Red mud	0.280	0.180

Source: United Nations (1988).

TABLE 6.7 Activity of Naturally Occurring Radionuclides in Metal Slags

	Concentrations (Bq/g)		
Slag	Ra-226	Th-232	K-40
Iron[a]	0.089	0.006	0.009
Steel	0.126	0.007	0.021
Copper	0.762	0.052	0.636
Nickel	0.518	0.778	0.076

[a] Refers to iron-chromium-carbon slag.

Source: Ettenhuber and Lehmann (1986).

steel under the same assumptions (Steiner 1993b; Dehmel et al. 1992). Up to 4 t of slag can be generated for each ton of copper produced (Jolly et al. 1993), but 2-3 t are more typical. Slag can be a marketable by-product for uses such as railroad ballast or for incorporation into concrete. Typically, however, the slag is left in piles around the smelting site (Davenport 1993).

The principal solid waste in aluminum production is a caustic bauxite residue (often called "red mud") containing large amounts of iron, titanium, phosphorus, and other elements originally present in lateritic ores. For each ton of aluminum produced, about 2 t of the bauxite residue is discharged (Carwile 1993). This residue is generally kept in large ponds until it settles and dries; the dried residue is then placed in a landfill. The U.S. Environmental Protection Agency (USEPA 1990a) recently ruled that the residues are not subject to regulation as hazardous waste. However, there is so much of this residue that the issue of its storage must be addressed. Attempts are being made to grow vegetation over these dried ponds to keep the caustic dust from damaging surrounding land and water.

6.2.3.3 Water Use Impacts

Mining and refining of iron ore, copper, aluminum (bauxite), lead, and nickel have serious impacts on water quality. However, a major problem involved in quantifying the effects of current metal mining is that about 60% of mine drainage is caused by abandoned mines (Koren 1991). Current mining may, therefore, affect water quality for many years in the future. In fact, the U.S. Environmental Protection Agency has determined that more than 80 old mining sites qualify for Superfund cleanup (Milius 1992). One of the primary problems with abandoned mines is that when mining operations cease, water is no longer

pumped from them. The mines can then flood, and the overflowing water can contain harmful contaminants that can seep into groundwater.

Estimating the amount of wastewater generated by a mining site is difficult because of the many differences in mines. Copper mines exemplify this problem — estimates of wastewater production range from 0 to 300 L of water per ton of ore from open-pit mines and from 8 to 4,000 L water per ton of ore from underground mines. These values become especially significant on a per-ton-of-metal basis, because 99 t of copper ore is needed to produce 1 t of copper metal. The open-pit mine thus generates up to 29,850 L of wastewater per ton of copper metal, while the underground mine generates up to 398,000 L of wastewater per ton of metal (Syracuse Research Corp. 1990).

Water pollution from metal mining can affect both surface water and subsurface water (groundwater). These water sources are differentiated because the effects and treatment of contamination are somewhat different. Groundwater pollution is a special problem because reclamation of polluted groundwater is more difficult and expensive than reclamation of surface water (Keller 1988). Once groundwater is contaminated, it can be a long-term condition that may persist for hundreds of years.

Acid mine drainage affects subsurface mines especially, although it can also be a problem for surface mines. Acid mine drainage occurs when aerobic bacteria convert sulfide compounds found in mines, waste rock dumps, and tailings ponds to sulfuric acid. Because of their high sulfur concentrations, copper, lead, and nickel ores are most commonly associated with acid mine drainage problems (Young 1992a). Rain and melted snow seeping through the mine or mine tailings transfer the acid to nearby rivers and streams and into the groundwater, destroying aquatic life and contaminating water supplies (Miller 1991).

The sulfuric acid lowers the pH of the water, which in turn increases its capacity to carry metal ions. As the acidic water travels over or through soils, it strips other metals from exposed rock, adding to the acid mixture trace elements such as lead, mercury, manganese, cadmium, and arsenic (Darlington 1992) and metals such as copper, cobalt, zinc, aluminum, and iron (Connolly and Kealy 1990). When these elements are leached out, they may be concentrated in water, soil, or plants, and when ingested may be toxic or carcinogenic.

Recently the U.S. Bureau of Mines found that in the U.S.A., where mining regulations are stringent and relatively strictly enforced, more than 19,000 km of rivers and streams and 73,000 ha of lakes and reservoirs have been poisoned by acid mine drainage (Darlington 1992). In one case of pollution from abandoned mines in the U.S.A., over 100 years of copper mining near Butte, Montana, polluted drinking water and soil with arsenic and other trace metals and tainted approximately 225 km of waterways. The U.S. Environmental Protection Agency designated four Superfund sites in that region, the largest cleanup area in the country (Milius 1992). Such effects may be more serious in countries where mining regulations are either nonexistent or poorly enforced and where drinking water is not treated before use.

In addition to the effects caused by acid in mining and milling water, problems can also occur because of the presence of naturally occurring radioactivity in the wastes. Copper and bauxite, especially, are associated with concentration of natural radiative elements. Acidic mine drainage can augment the level of radioactivity in surface waters by leaching out uranium and its radioactive decay products from waste storage piles. Radiological analysis of copper mine pumpout water at several sites in the U.S.A. shows a range of 0.056 to 1.01 Bq/L for Ra-226 (Fitzgerald 1976). This phenomenon has not been extensively studied and thus remains a relatively unrecognized hazard to workers and the general public.

Surface mine sediment production can be 10 to 60 times the amount of sediment from lands used for agriculture (Koren 1991). Suspended sediment in rivers and lakes can be a serious problem, and is, by volume, the greatest surface water pollutant, reducing the quality of water resources and potentially depositing toxic elements on cropland (Keller 1988). The deposited sediment blocks waterways used for transportation and fills the area behind dams, requiring removal to maintain their usefulness.

Metal refining processes have been responsible for water quality problems as well, although these problems are significantly less now than in the past because of more stringent environmental regulation and technology improvements throughout the world. Also, smelting and refining impacts can be controlled somewhat better than mining impacts because the smelting and refining occur inside a structure rather than in open spaces. Liquid effluents from refining and smelting of nonferrous metals in Western Europe, North America, and the former Soviet Union have been found to contain a variety of toxic or carcinogenic trace elements (Nriagu and Pacyna 1988). These elements were listed in Table 6.3 (Section 6.2.3.1). The data presented are for both primary and secondary smelters. Primary nonferrous smelters process virgin ore almost exclusively, while secondary smelters process mostly scrap metal.

6.2.3.4 Energy Use Impacts

Estimates of energy use in production processes can vary widely among companies and countries, depending on such factors as the age of the plant and the energy sources available in the region. Regardless, for each metal, refining accounts for a majority of the energy used. Of the metals considered here, aluminum production uses the most energy and lead the least.

Energy requirements just for the extraction of iron from the ore to make steel, are about 19.4 MJ per ton of pig iron (St. Pierre 1992). Information from the American Iron and Steel Institute indicates that the total basic oxygen process in 1991 used 28.7 GJ per ton of steel. Worldwide, the range is typically from 21 to 35 GJ or more per ton. Making steel from scrap requires approximately 10.5 GJ/ per ton, less than a third of the energy requirement when ore is the starting point (Steiner 1993a).

According to the U.S. Bureau of Mines, the final reduction stage of aluminum production is the most energy-intensive. Mining, breaking, loading, hauling, crushing, and

drying collectively require only 1.16-3.49 GJ of the overall 132-170 GJ required per ton of primary aluminum metal (McCawley and Baumgardner 1985). The wide range of values is caused by many factors, including the age of the reduction cell, the type of anode system, the efficiency of the system, and the amount and type of transportation that is involved in the process. These energy requirements are slowly being reduced as new technology is discovered and implemented. Aluminum beverage containers made from scrap require 95% less energy than those made from ore (Lund 1993).

For typical ore grades and treatment of standard ore concentrates of copper, Castle (1989) found energy requirements for mining, beneficiation, and drying of copper to be 66.3 GJ per ton of metal. The total energy requirements for smelting and further refining ranged from 27.4 to 31.3 GJ per ton, depending on the process. Copper production from ore requires from two to six times more energy than production from scrap (Jolly et al. 1993). The Organization for Economic Cooperation and Development (OECD 1991) suggests that there is an 87% saving in energy use from substituting scrap for ore.

As of 1985, energy requirements for lead production, including mining, concentration, smelting, and refining processes, were the lowest of any of the major metals. Approximately 25.2 GJ is required for mining and concentrating one ton of lead. The total energy to mine, concentrate, and refine one ton of lead ranges from 39.8 to 42.2 GJ (Castle 1989).

The two major types of nickel deposits (sulphidic and lateritic) are mined and handled by different methods. For typical ore grades and treatment of standard ore concentrates of nickel, energy requirements can be as low as 84.4 GJ per ton for underground nickel sulphide mining and as high as 219.8 GJ per ton for nickel laterite open-pit mining (Castle 1989). Energy requirements for smelting and refining of nickel are very high, depending on the ore type and process. For sulphide nickel, energy requirements are 152.4 GJ per ton for flash smelting, while requirements for laterites range from 249.8 GJ per ton for acid pressure-leaching to 472.1 GJ per ton for the ammonia leach process.

6.2.4 Coal Mining and Coke Production Processes

Production of steel involves the use of coke, which is produced from metallurgical (or coking) coal. Thus, the impacts of steel production include the environmental effects and risks associated with discharges from the mining, preparation, storage, and transportation of coking coal, as well as those from the production of the coke from that coal. These impacts and risks are summarized in the following subsections.

6.2.4.1 Coal Mining

Coal seams deeper than about 60 m usually require underground mining. The major underground mining methods currently used in the U.S.A are room-and-pillar and longwall panel mining. In room-and-pillar mining, coal is removed from intersecting tunnels in the coal seam; coal pillars are left in a checkerboard pattern to provide roof support and reduce

subsidence. As mining depth increases, the size of the support pillars must also increase (DOE 1988). Panel mining, which can only be used where geological conditions are favorable and subsidence can be tolerated, eliminates the need to retain coal pillars for roof support. Longwall mining is the predominant method of panel mining; continuous mining equipment is used to cut two parallel operating tunnels into a coal seam. Room-and-pillar methods are used in 96% of all underground mines in the U.S.A. Longwall mining is widely used in Europe (DOE 1988), particularly in the United Kingdom and the Federal Republic of Germany. Continuous long-wall mining is the predominant coal mining method in Poland, where the mines are deep and the seams are thinning (Szpunar et al. 1990).

Surface mining of coal is accomplished by area, contour, auger, and open-pit methods. Topsoil and overburden are removed by cutting successive trenches (typically 30-60 m wide and 0.5 km or more long) to expose the top of the coal seam. Following coal extraction, another trench is cut to expose more coal; the new overburden (referred to as "spoil") is used to fill the mined-out trench. Spoil piles are then graded, topsoil (if segregated) is replaced, and the land is revegetated. Up to 40 t of overburden may be handled for each ton of coal recovered (DOE 1988).

Coal preparation technologies may be physical or chemical. Both types of technologies are preceded by crushing to reduce the size of the coal, and screening to remove the fines. Physical coal cleaning processes remove impurities such as shale, clay, and pyrites. The technologies employed are mature and widely used in the eastern U.S.A., where most, if not all, of the metallurgical coal is mined. About 50% of underground-mined coals and about 25% of surface-mined coals in the U.S.A. are physically cleaned. Physical cleaning processes primarily rely on differences in specific gravity, but may also use differences in surface properties, magnetic and electrical characteristics, or other attributes to separate impurities that are physically bound within the coal. Wet-cleaning methods account for about 98% of physical cleaning activities (DOE 1988). More expensive chemical means must be used to remove additional impurities that are chemically bound in the coal, such as organically bound sulfur.

The major modes of transporting mined coal are railroad, truck, and barge. Trucks, conveyor belts, and pneumatic pipelines are economically used for short-haul coal transport. About 14% of the coal produced in the U.S.A. is moved by trucks, generally over intermediate distances of 80-120 km. Truck transport is a relatively expensive mode. Conveyors and pneumatic pipelines typically are used to deliver smaller amounts of coal over shorter distances (less than 15 km) (DOE 1988).

6.2.4.2 Coke Production

Coke is a premium fuel produced from a blend of two or more bituminous coals, because individual coal types do not possess all the properties required to produce high-quality metallurgical coke. Coal is converted into coke, a porous, solid, carbonaceous material derived from the thermal decomposition of plastic or caking coals in the absence of air (DOE 1992a). Table 6.8 compares and summarizes U.S.A. coal and coke production and consumption statistics for 1970, 1980, and 1990.

TABLE 6.8 Consumption/Production Statistics for U.S.A. Coal and Coke, 1970, 1980, and 1990

Category	1970	1980	1990
Coking coal consumption (10^6 t)	87.5	60.5	36.1
Coke production (10^6 t)	60.3	41.8	25.0
Coke consumption (apparent) (10^6 t)	57.3	37.5	25.2
Coke used per ton of pig iron[a] (t)	0.63	0.58	0.50
Operating coke plants (number)[b]	69	60	34

[a] See discussion in text regarding technological advances in blast furnace operations and increase in electric-arc furnace usage.

[b] Reduced to 28 coking plants by 1992 (USEPA 1992a).

Source: DOE (1992a).

A large fraction of the coal (vitrinite) softens when heated to about 400°C and decomposes, releasing volatiles. After a plastic or molten mass is formed in which individual coal particles lose their identities, a stage of minimum viscosity occurs, followed by a stage of increasing viscosity as a second group of volatiles is released. The mass solidifies into a carbon-rich material, referred to as semicoke. Continued application of heat in the range of 500-900°C converts the semicoke to coke by driving off essentially all elements except carbon, the inorganic mineral elements, and trace amounts of oxygen, nitrogen, hydrogen, and sulfur. The residual resolidifies as shiny, hard, black coke (Neavel and deMasi 1978).

Commercially, coals are coked in ovens called slot ovens. These ovens are refractory-lined containers typically 0.5 m wide, 6 m high, and 40 m long. From 30 to more than 100 of these ovens are often aligned side-by-side into a battery, each oven separated from its neighbor by a narrow space referred to as a flue. Coal is charged through ports along the top of the oven until it fills the oven to within several feet of the top. Depending upon size, each oven holds 12-40 t of coal. Heat is applied through the side walls by burning, in the flue, either natural gas or combustible gases derived from the pyrolysis of the coal itself (coke oven gas) (Neavel and deMasi 1978).

Flue temperatures are commonly controlled at 1200-1300°C, which allows coking to proceed at 25 mm an hour. Since a typical slot oven is 0.5 m wide, a complete coking cycle takes about 18 hours with the plastic zone, about 2.5 mm thick, moving progressively from the wall toward the center of the charge. Volatile products evolve toward the center and then upward, where they are removed from the head space through an offtake system composed of stand pipes and other piping. Tars and oils are then separated from aqueous liquor and gases. The gas (rich in methane) is scrubbed and used to fire the oven; tars and oils are either burned as fuel or further processed into by-products. A small, positive back-pressure maintained on the oven prevents air from leaking into the ovens during coking (Neavel and deMasi 1978; American Iron and Steel Institute undated; USEPA 1992a).

At the completion of the coking cycle, the hot, incandescent coke is transported by a rail car to a quenching shed where it is cooled with water sprays. The coke is then crushed and screened to produce pieces sized commonly between 1 and 5 mm. Fine pieces of coke (breeze) are screened out and used as fuel (Neavel and deMasi 1978; USEPA 1992a).

6.2.5 Health Risks of Coal Mining and Coke Production

6.2.5.1 Workers

Coal mining has historically been a hazardous occupation. The incidence of injuries and deaths due to accidents in underground and surface coal mines and their associated coal preparation plants is listed in Table 6.9. Also listed is the health risk in fatalities on the basis of transport mode. The occupational fatalities include (1) fatal accidents in coal mines, (mainly from roof cave-ins and machinery); (2) miners' diseases (exposure to dust leading to pneumoconiosis, silicoses, bronchitis, vasoneurosis, vibration disease associated with equipment use leading to muscle and bone pains, bursitis, and Raynaud's syndrome); and (3) fatalities during transport (IAEA 1991).

The primary concerns for underground mine worker health and safety have been safe operating parameters, specifically for dust control, ventilation, and roof support. The prime health concern is coal worker pneumoconiosis. The incidence and severity of this disease is believed to be related to the levels of dust present in mines. Other occupational health problems, such as loss of hearing, nonrespiratory illness from coal exposure, and hypertension, are suggested from epidemiological studies, but the extent of these problems is not well known (DOE 1988).

The new chemical cleaning technologies may result in the release of chemicals such as iron pentacarbonyl, hydrogen sulfide, and organic solvents that can produce health effects ranging from eye irritation to serious illness or death, depending on exposure levels. The handling and conversion of coal that contains residual amounts of cleaning agents may also present both occupational and public health concerns (DOE 1988).

Potential occupational hazards have also been identified for coking operations. Epidemiological studies showed that U.S.A. steel workers most heavily exposed to mixtures of organic pollutants in coke oven emissions at by-product plants (e.g., at the topside of the coke oven) had an eightfold higher rate of respiratory cancer than the general U.S.A. population (USEPA 1984b, 1992b).[3] Thus, coke oven emissions became regulated under the U.S. Occupational Safety and Health Administration (OSHA) to improve safety in the work environment (Shobert 1987).

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[3] The studies also showed that 90% of these workers were nonwhite.

TABLE 6.9 Quantifiable Resource Requirements, Discharges, and Impacts from Coal Mining, Coal Preparation, Coal Storage, and Coal Transport per Ton of Steel Produced[a]

Category	Quantity, by Mine Type	
	Underground Mining	Surface Mining
Resource Requirements		
Coke[b] (t)	0.5	0.5
Coal[b] (t)	0.72	0.72
Water (L)	102	601
Land (ha)	0.28×10^{-6}	6.5×10^{-6}
Atmospheric Emissions		
Particulates (g)	0.34	24
Hydrocarbons (g)	0.34	30
SO_2 (g)	0.42	34
CO (g)	4.5	97
NO_x (g)	Negligible	466
Aldehydes (g)	Negligible	7.2
Fugitive dust	Negligible	1.3-2.2

Category	Underground Mining		Surface Mining	
	Mine	Prep Plant[c]	Mine	Prep Plant[c]
Water Discharges				
Appalachian				
Fe (g)	5.7	1.8-4.1	7.5	1.8-4.1
Mn (g)	3.2	1.0-2.3	4.2	1.0-2.3
Total suspended solids (g)	57	18-41	7.5	18-41
Interior				
Fe (g)	3.9	1.8-4.1	2.5	1.8-4.1
Mn (g)	2.2	1.0-2.3	12.6	1.0-2.3
Total suspended solids (g)	39	18-41	25	18-41
Worker Health and Safety Impacts (excluding transportation)				
Deaths[d]	2.8×10^{-7}	4.5×10^{-9}	3.6×10^{-8}	1.8×10^{-8}
Injuries	3.5×10^{-5}	6.0×10^{-7}	3.8×10^{-6}	2.4×10^{-6}

TABLE 6.9 (Cont.)

Category	Rail	Truck	Barge	Pipeline
Coal Transport Deaths[e]				
Workers	5.4×10^{-11} to 7.9×10^{-9}	5.0×10^{-9} to 8.6×10^{-7}	2.2×10^{-8} to 3.6×10^{-7}	5.8×10^{-8}
Public	1.3×10^{-7} to 1.9×10^{-7}	2.2×10^{-7} to 8.6×10^{-7}	2.5×10^{-8} to 1.0×10^{-7}	NA

[a] Based on U.S.A. eastern coal mines; U.S.A. western coal mines generally do not produce metallurgical-grade coal.

[b] From DOE (1992a); 1 t coal produces 0.69 t coke; 0.5 t coke is used to produce 1 t pig iron; thus, assume 0.72 t of mined coal is used to produce 1 t steel.

[c] Associated coal preparation plant.

[d] IAEA (1991) gives a range of 8.6×10^{-8} to 6.0×10^{-7} for underground mines and 3.2×10^{-8} to 6.1×10^{-8} for surface mines.

[e] From IAEA (1991).

Source: DOE (1988), except as noted.

Coke oven emissions are highly variable and not easily measured since emissions escape from many different pieces of equipment, and leaks can change in size and location over time. Also, the tar component of coke oven emissions condenses on measurement equipment, causing erroneous results. For these reasons, proposed regulations address only visible emissions that are estimated (in terms of duration) by operators. Among the 10 states in the U.S.A. currently regulating by-product coke oven emissions, limits on charging operations range from 11 seconds to 60 seconds (on average) of visible emissions per charge (Hootman and Vernet 1991; USEPA 1992c).

Dust emissions have been measured from West German coke oven plants employing dust removal technology. These emission levels can be used to approximate the level per ton of U.S.A. steel produced (Table 6.10). Topside leak rates of POM can range from an average of 0.002 kg/h to 0.013 kg/h per oven, which may be equivalent to 36-234 g per oven per charge (Hootman and Vernet 1991; Elliott 1981).

To protect the worker, USEPA standards have been proposed for coke oven emissions. Industry experts have estimated that setting limits on cancer risks downwind of coke ovens would shut down nearly all of the nation's 28 plants (down from 69 in 1970 [Table 6.8]), eventually halting steel production in the U.S.A. Reportedly, it is uncertain

TABLE 6.10 Types and Quantities of Environmental Impacts, Effects, and Risks from the Coking of Coal and Related Processing[a]

Category	Direct Impact	Resultant Health/ Environmental Effect	Quantifiable Effect[b-i]	Value
Worker health and safety[g,j]	Emissions of benzene, toluene, xylenes, particulate POM, trace elements — As, Be, Cd, Cr, Pb, and Ni — and other VOCs and HAPs.	Death, injury, respiratory (lung) and kidney cancer, other respiratory ailments (such as bronchitis), and heart disease from occupational exposure.	Topside coke oven POM	0.65-4.2 g
			Carbon emissions (with modern doors)	2.2-7.1 g
			Total PAH	3.9 g
			Dust emissions	
			Charging	7.5 g
			Pushing	20 g
			Quenching	35 g
			Lung cancer risk: increase over baseline risk.	0.4-15 times
Public health and safety	Emissions of benzene, toluene, xylenes, particulate POM, trace elements — As, Be, Cd, Cr, Pb, and Ni — and other VOCs and HAPs.	Death, respiratory cancer, and other ailments from public exposure (sensitive individuals).	Excess lung cancer deaths	1.39×10^{-6} (1972) 2.06×10^{-8} (1991)
			Excess total cancer deaths	7.34×10^{-8} (1985)
			Lost work days	2.5×10^{-5}
			Reduced activity days	1.5×10^{-3}
			Direct medical expenses	1.2 mills
Air quality	(Incorporated above in public health and safety.)		Benzo(a)pyrene	1.33 g (1970s)
Water quality	Discharges from coking operations.	pH changes and levels of pollutants in water sink affecting quality and availability for terrestrial and aquatic ecologies.	Effluent standards (West Germany)	
			Suspended solids	7.5 g
			Chemical oxygen demand	30 g
			Biological oxygen demand	4.5 g
			Inorganic nitrogen	12 g
			Total nitrogen	15 g
			Phenol	0.075 g
			Phosphorus	0.45 g
			Cyanide	0.015 g
			Thiocyanide	3.0 g
			Benzene, toluene, xylenes	0.015 g
			Benzo(a)pyrene	0.015 g
			Sulfide	0.015 g

[a] Sources of identified risk: coke (slot) oven (primary source), coke quenching process step, and blast furnace operation. Risks are calculated per ton of steel produced (where applicable). POM = polycyclic organic material, VOCs = volatile organic compounds, HAPs = hazardous air pollutants; PAH = polynuclear aromatic hydrocarbon.

[b] Dated, but illustrative, material -- based on (1972) emissions: Suta (1977) from DOE (1980).

[c] EPA (1992a).

[d] Elliott (1981, p. 866).

[e] Anon. (1993).

[f] Dong et al. (1988); lifetime lung cancer risk to a U.S.A. or Canadian nonwhite male worker exposed to coke oven emissions for 40 years, beginning at age 20 (not given in terms of steel produced, but calculated on annual basis).

[g] USEPA (1990b).

[h] Fisher (1992).

[i] Friedrich and Hinz (1992).

[j] Minority workers estimated at 90%, with an eightfold higher rate of respiratory cancer observed USEPA (1984b) from EPA (1992b).

whether risks to the general public, which the Clean Air Act Amendments are designed to protect, are similar to those of exposed workers. However, it is generally agreed that coke production liberates a large amount of organic chemicals as by-products and that without emission control technology coke plants will continue to be serious air polluters (Shobert 1987).

6.2.5.2 Public

Coke oven emissions, characterized typically by oily, yellow-brown smoke, contain more than 10,000 individual compounds as gases and respirable particulate matter. The most critical components, in terms of public health concerns, appear to be the volatile organic compounds, benzene, and toluene. In addition, certain trace elements are also emitted from coke ovens. These elements — arsenic, beryllium, cadmium, chromium, lead, and nickel — pose health risk concerns over long-term exposure. Finally, certain gases such as methane (CH_4), hydrogen sulfide (H_2S), CO, and nitric oxide (NO) are also emitted (Hootman and Vernet 1991; Szpunar 1992; USEPA 1992c). Detailed descriptions of the health effects associated with these substances are included in Appendix E.

In 1992, about 23 x 10^6 people were estimated to have been exposed to toxic emissions released from doors, topside, and charging at 28 coke oven plants. The cancer risk assessment indicates the following: 1.8 excess cancer cases per year due to baseline levels of coke oven emissions, 2,200 additional lost work days, 13,000 additional reduced activity days, and an extra $103,000 ($1991) in direct medical expenses (EPA 1992a).

6.2.6 Environmental Impacts of Coal Mining and Coal Production

Coal mining, preparation, storage, and transportation impact air, water, solid waste and land use, noise, and health and safety. Many of the environmental impacts of coal mining and preparation are unavoidable. For instance, short-term loss of wildlife habitat and agricultural production is inherent in surface mining. Table 6.11 summarizes qualitatively by category the direct impacts, the resultant health and environmental effects, and the specific source and level of identified risk.

6.2.6.1 Air Impacts

Extraction, storage, transfer and transportation, and preparation and cleaning of coal and waste storage all produce some level of atmospheric emissions. Table 6.11 lists literature-derived estimates of atmospheric emissions in the eastern U.S. generated by underground and surface mines capable of producing metallurgical coal, calculated per ton of steel produced (DOE 1988). (Typically, U.S.A. western surface mines do not produce metallurgical-grade coal, only subbituminous and bituminous ranks of steam coal.)

TABLE 6.11 Identification of Environmental Impacts, Effects, and Risks from Coal Mining, Coal Preparation, Coal Storage, and Coal Transportation[a,b]

Category	Direct Impact	Resultant Health/ Environmental Effect	Source of Identified Risk	Level of Risk
Air quality	Emissions of particulates, SO_2, CO, NO_x, ozone, airborne Pb, VOCs, and numerous other HAPs.[c,d]	Harmful to human health and terrestrial ecology; can cause death, injury,[e] carcinogenicity, respiratory ailments,[f] eye damage, slower plant growth, crop and forest damage, loss of habitat, materials corrosion and soiling, climate change, recreation diminishment, degradation to scenery, and visibility impairment.	Surface mining	Low
			Uncontrolled fires from abandoned mines and storage/waste piles	Low to medium
			Prep plant (esp. thermal dryers)	Low
			Combustion products from chemically cleaned coal	Medium
			Storage and transfer	Low
Water quality	Discharges from mines, prep plants, and slurry pipelines; runoff from storage/ waste piles and reclaimed land.	Can affect pH and levels of pollutants, harming water quality and aquatic life.	Surface-mine discharge	Medium
			Underground-mine discharge	Medium
			Storage/waste-pile runoff	Medium
			Prep-plant discharge	Low
			Aquifer modification	Low to high
Water quantity	Reduction/redirection of surface water and groundwater supplies.	Can affect water availability for terrestrial and aquatic ecologies and other uses.	Surface-mine-drainage modification	Low
			Aquifer modification	Low to high
			Consumptive uses	Low to high
Land use/ waste disposal	Abuse of land during and after mining; aesthetic scarring, esp. from surface mines; formation and collection of mine and prep-plant wastes.	Loss of wildlife habitat ranges from temporary to permanent.	Surface-mine reclamation	Low to medium
			Subsidence	Low
			Wildlife habitat destruction	Low to medium
			Mine-waste and prep -plant disposal	Low
Noise	Temporary or permanent loss in hearing sensitivity, physical, and psychological disorders; interference with speech communications; changes in cardiovascular, neurologic, and other functions (from machinery or blasting).		Surface mining	Low to medium
			Underground mining	Low to medium
			Prep plant	Low
			Storage	Low
Worker health and safety; public health and safety	Fatalities and disabling injuries from mining, prep-plant, and transportation accidents; respiratory illness from mining; nonrespiratory illness from coal exposure; exposure to hazardous materials in prep plant; hypertension; socioeconomic effects from increased transportation.		Surface mining	Low
			Underground mining	Low
			Prep-plant operation:	
			- physical and	Low and
			- chemical	medium
			Storage	Low
			Transportation	Low

See footnotes on next page.

TABLE 6.11 (Cont.)

[a] DOE (1988).

[b] Szpunar and Gillette (1992).

[c] The list of hazardous air pollutants (HAPs) includes 189 chemical species, including specific organic compounds, inorganic elements and their compounds, and chemical classes or categories. The class of polycyclic organic matter (POM) is included in this list (U.S. Congress 1990).

[d] Szpunar (1992).

[e] Increased risks of injury (morbidity include: acute effects, exacerbation of chronic illness, and increased risk of developing chronic diseases from involuntary exposure.

[f] Specific respiratory ailments include impaired breathing, coughing, chest tightness, reduced productivity and activity, altered pulmonary ventilation, increased frequency and severity of asthmatic attacks, increased prevalence of chronic respiratory disease, and increased mortality.

Most of the atmospheric emissions from surface mines are fugitive dusts from access and haul roads and from coal loading, transfer, processing, and storage operations. Sources of fugitive dust can be controlled by spraying the coal with chemicals or water. Dust problems at transfer points may be reduced by the use of electrostatic precipitators, fabric filters, or even well-designed buffer zones. Emissions from conveyors are effectively eliminated by covers. Windbreaks can effectively reduce visible dust emissions from wind erosion of coal and overburden. Underground mining, because of the lower exposure of activities to surface winds and greater use of electrical equipment, generally produces fewer atmospheric emissions than does surface mining (DOE 1988).

Uncontrolled fires resulting from spontaneous combustion in abandoned mines and waste piles containing carbonaceous materials can smolder for years, producing toxic gases. Because such fires burn under oxygen-deficient conditions, the emissions differ from those generated during oxygen-rich combustion such as that typical of a coal-fired power plant boiler. By reducing air circulation in abandoned mines and by compacting and/or burying refuse piles, fires may be prevented (DOE 1988).

Sources of air pollution from coking plants may be broadly defined as either continuous or fugitive. The main sources of continuous emissions are those that originate from combustion processes such as battery underfiring, steam raising, and ammonia incineration. The main pollutants emanating therefrom include SO_2, NO_x (principally nitric oxide, NO), and particulates (Fisher 1992). The most widely applied SO_2 control methods in Europe are ammonia-based removal processes. The control of NO_x is achieved by the application of low-NO_x burners and the incorporation of staged combustion. Particulates, primarily from incomplete combustion, can be controlled to some extent by adjusting and maintaining the burners (Fisher 1992).

In most countries, it is the fugitive emissions are generally the hardest to control. Fugitive emissions from the battery operations contain significant concentrations of particulates, PAH, benzene, toluene, xylenes, H_2S, and heavy metals. A German study has

established that antimony, arsenic, beryllium, cobalt, chromium, copper, manganese, nickel, and vanadium are largely retained in the coke, whereas cadmium, lead, mercury, thallium and zinc are more concentrated in the tar (Eisenhut 1990; Fisher 1992).

Old coke ovens have been estimated to produce 7.8 g of PAH per ton of coke (equivalent to 3.9 g of PAH per ton of steel produced) attributed to door leakage (48%) and leaking charge hole lids (42%) (Fisher 1992). In the 1970s, coke oven emissions were reportedly one of the major sources of the organic compound, benzo(a)pyrene (one compound in the class of POM), accounting in 1972 for 154 t of emissions, or about 20% of the nationwide benzo(a)pyrene emissions from all sources (Suta 1977; DOE 1980). This amount was equivalent to 1.33 g benzo(a)pyrene per ton of steel produced at that time. Actual downwind measurements indicate the influence of a coking plant on the background levels of PAH, benzene, toluene, and xylenes with a range of 1-2 km. However, recent European studies demonstrate reduction of PAH emissions to 1-2% with modern self-sealing door designs. Battery emissions of benzene, toluene, and xylenes at well-maintained modern coke plants are estimated at less than 6% of those from older installations. At British Steel Corporation, for example, oven door and oven top-leakage control have averaged greater than 99% since start up of its rebuilt ovens in 1984 (Fisher 1992).

6.2.6.2 Land Use Impacts

The effects of coal mining on land use are direct and site specific. Surface disruption, inadequate reclamation of surface mines, subsidence from underground mining, and disposal of wastes are the major impacts. The most obvious impact of surface mining is the temporary removal of land from its primary use as farmland, forest, or rangeland (DOE 1988).

Contour mining can create severe environmental problems if not properly performed. Spoil from improperly controlled mines can result in erosion and landslides, and unreclaimed highwalls are a major aesthetic problem. However, experience in most coal-producing regions suggests that once the coal has been extracted, the land can be successfully reclaimed to support its former uses (DOE 1988). Inadequate reclamation of surface-mine areas may leave the land unable to support desirable plant species and result in the loss of important farmland or wildlife habitat. Measures to mitigate these potential impacts will vary with the site, but can include segregation of topsoil and overburden, better compaction of refuse, revegetation with native species, combination planting, and soil enrichment (DOE 1988).

Although less conspicuous than the results of surface mining, subsidence from underground mines can have severe impacts on roads, water and gas lines, buildings, and local hydrology. The extent, severity, and timing of subsidence depend on the overburden composition and thickness, mining technique, and other factors. It has been estimated that about 25% of the 8×10^6 acres of undermined lands in the eastern U.S.A. have subsided (DOE 1988).

Another major land use impact from coal mining and preparation results from the disposing of mining wastes. In 1979, there were an estimated 3,000-5,000 waste piles in the

eastern U.S.A. that together contained over 3×10^9 t of waste. In addition to degrading air and water quality, mine wastes can be a blight on property values and become a visual affront, unless they are properly disposed of and the land is reclaimed effectively. In 1971, improper disposal of such wastes was dramatized in Buffalo Creek, West Virginia, where a water impoundment that was constructed of mine wastes broke during a heavy rainstorm, killing more that 125 people and causing millions of dollars in property damage. Numerous other such impoundments in the eastern U.S.A. present similar dangers (DOE 1988).

Coal preparation plants are by far the largest producers of solid waste from underground mining. This waste consists of shale, pyrites, coal fines, and impurities. About 25% of the raw coal from both surface and underground mines that is cleaned becomes solid waste. Surface mines also generate large amounts of material from overburden removal. However, most of this material is returned during the mine area reclamation, with little net solid-waste generation (DOE 1988).

6.2.6.3 Water Impacts

Historically, water quality degradation has been one of the major environmental concerns associated with coal mining and preparation. Adverse impacts can result from water drainage from mines, preparation plant wastewater, leaching and erosion of solid wastes from mining and cleaning plants (rainwater runoff), slurry dewatering, and modifications of aquifers during mining. The water quality factors of greatest concern are alkalinity or acidity (pH), dissolved and suspended solids, and the concentrations of various metals. Table 6.9 lists literature-derived estimates of water discharges by U.S.A. metallurgical region, calculated per ton of steel produced (DOE 1988). However, no discharge of process water from new coal preparation plants is allowed under the New Source Performance Standards (NSPS) (USEPA 1985).

Acid drainage from both underground and surface mines and from coal and refuse storage piles is a potentially severe environmental impact where the coal seams and overburden are rich in pyrites (sulfide impurities). During mining, pyrites may be exposed to air and water and may become oxidized to form sulfuric acid. The resulting lower pH increases the solubility of compounds containing toxic heavy metals such as arsenic, cadmium, chromium, lead, mercury, and nickel. The acidity and solubilized trace metal pollutants may become toxic to aquatic life and can render water unfit for municipal and domestic use. And although effluent limitations exist to control acid drainage from new mines, drainage from abandoned mines continues to be a lingering problem. Based on data collected in the 1960s, about 10,000 miles of streams, primarily in Appalachia, had been degraded by acid drainage and sedimentation; three-fourths of the total acidity was attributed to abandoned mines (DOE 1988).

Aquifer modification is another form of water quality degradation. It occurs from the interconnection of vertically adjacent aquifers and by seepage of contaminants from spoil or

waste disposal piles. Adjacent aquifers can be contaminated by drainage through joints and fractures created during blasting or intrusion into the aquifers during mining (DOE 1988).

Groundwater impacts from mining in or near aquifers and recharge areas are site specific. Diversion of local surface water drainage may affect both regional hydrology and erosion patterns, which in some cases results in unacceptable levels of sedimentation and stream flows that are inadequate to sustain aquatic life. Where a mine is located below the water table, seepage of water into the mine can lower the water table and dry up wells in the area. The permeability and recharge capability of postreclamation soil may be significantly different from that of virgin soil; altered groundwater recharge and surface flooding are the potential results (DOE 1988).

Concentrations of pollutants in treated effluents from coal preparation plants can be comparable to those in effluents from active mines. The volume of discharges per ton of coal can also be similar. Therefore, the quantity of a pollutant that is discharged to a stream from cleaning a ton of coal may be about the same as the quantity from mining a ton of coal, resulting in double the discharge per single ton of coal. The types of effluents will depend on factors such as coal characteristics, the type of cleaning technology, control practices, and rainfall (DOE 1988). The annual water requirements for mining and preparing 1×10^6 t of raw coal by eastern U.S.A. underground and surface mining are 1.5×10^8 L and 8.3×10^7 L, respectively (DOE 1988). These water use requirements translate to 102 and 61 L per ton of steel produced.

Traditionally, the treatment of coke oven waste water has been a three-stage process involving pretreatment for the separation of oils and tars, steam stripping for the removal of ammonia, and biological oxidation and accompanying stages for the destruction of phenols, thiocyanates, cyanides, thiosulfates, and other compounds that contribute to the chemical oxygen demand of the effluent. Heavy metal concentrations in waste water are considered negligible (Fisher 1992).

6.2.6.4 Noise Impacts

The coal preparation crusher and other mining and transportation equipment are the major sources of noise from both surface and underground mining. Blasting, which is normally carried out intermittently at strip mines, results in a sharp peak superimposed on the normal background noise level. Heavy construction equipment typically generates noise at a level of 80-100 decibels (dB) at 15 m. This noise level is reduced to 60-80 dB at distances of about 450-600 m from the noise source. As a reference, the American Conference of Governmental Industrial Hygienists has recommended maximum duration for noise exposure: a maximum daily exposure of 85 dB in an 8-hour shift and a maximum of 15 minutes at the 105-dB level (DOE 1988).

6.3 SUMMARY

Tables 6.12 through 6.14 summarize the available quantitative estimates of discharge and effects per ton of metal produced for iron ore/steel, copper, and aluminum, respectively. Data on land, water, and atmospheric impacts are included, as well as data on energy use and some health effects. Impacts of producing fuel or energy required for metal production are not included.

Many types of impacts are not included in the tables because sufficiently detailed data are not available. Among the impact categories that could not be included are the amounts of overburden, tailings, sedimentation, acid mine drainage, and dust produced per ton of metal, as well as the amount of land required for mining and refining operations.

Public health effects also are not fully accounted for on a per-ton basis. Radiation doses to workers and the public could not be appropriately quantified because adequate information on exposures was lacking, as was information on exposure to toxic elements. Fatalities from miners' exposure to radon were excluded because of the difficulty of converting estimates to a per-ton basis. Radiation and vehicle accident fatalities associated with transportation are similarly excluded. In addition, health effect data for workers only address acute injuries, not illnesses due to chronic exposure to toxic substances. Thus, the summaries of effects given in Tables 6.11 through 6.13 provide an incomplete picture of the total impacts of replacing RSM.

As industrialization increases throughout the world, the demand for metals follows this pattern of increase. To meet the worldwide demand, more ore must be mined and processed. One of the results of this continual and increased mining is a general lowering of the average ore grade, because superior deposits are mined first. This situation, in turn, means that increased quantities of ore will have to be mined to fill the worldwide demand for metals, which will result in increased environmental impacts, energy use, and risks to workers and the public unless additional precautions are taken.

Mining and smelting also involve international equity issues that must be considered. For instance, if the U.S.A. and other highly industrialized nations strengthen environmental regulations, mineral industries may relocate to developing countries with less stringent or poorly enforced environmental, health, and safety regulations. Thus, equity issues are important if environmental impacts are shifted from developed to less developed countries. Equity issues can also arise if minority or impoverished populations are disproportionately employed in the riskiest metal processing fields.

TABLE 6.12 Quantifiable Discharges and Impacts of Iron Ore/Steel Production per Ton of Steel Produced

Category	Material/Quantity	Environmental or Health Effects
Resource requirements	Ore[a]: 1.9 t Fluxes: 110 kg Coke: 0.5 t	Creates tailings piles; acid mine drainage (from ore, limestone, and coal mining) releases heavy metals, and toxins; disturbs and pollutes land, air, water, natural habitats; results in worker accidents, health risks.
Residual slag	BF[b]: 262 kg BOF[c]: 75-120 kg	May require disposal.
Heavy metals in wastewater from smelting and refining[d]	Pb: 0.2-0.4 ng/L	Causes neurological and urinary tract disorders; anemia, reproductive and respiratory dysfunctions; hearing loss; liver, kidney, and bone damage; learning disabilities in children; cardiovascular disorders; blood abnormalities.
	Mn: 2.0-5.2 ng/L	Toxic to infants; causes metabolic and intestinal problems, abnormalities and suppressed growth in plants and animals.
Heavy metals in air emissions from smelting and refining[d]	Sb: 0.005-0.1 g	Causes respiratory and circulatory dysfunction, gastrointestinal disorders; suspected carcinogen.
	As: 0.5-3.5 g	Causes skin abnormalities, skin and lung cancers, lung dysfunction, neurological disorders, hematological effects including anaemia.
	Cd: 0.04-0.4 g	Causes hypertension, sterility, testicular hemorrhage, renal dysfunction, kidney damage, fibrosis, hypertension, pulmonary disorders such as emphysema; suspected carcinogen (lung, prostate).
	Cr: 4-40 g	Causes respiratory dysfunction, papilloma of larynx and pharynx, lung and gastrointestinal cancers.
	Cu: 0.2-4.0 g	Causes respiratory irritation.
	Mn: 1.5-40 g	Toxic to infants; causes metabolic disorders, intestinal disorders, abnormalities and suppressed growth in plants and animals, neurological disorders, lung irritation and infections, impotence.
	Ni: 0.05-10.0 g	Causes pulmonary and immunological disorders, nasal and lung cancers, birth defects and malformations.
	Se: 0.001-0.003 g	Causes neurological disorders, hair loss, respiratory dysfunction.
	V: 0.1-2.0 g	Causes respiratory distress, neurological dysfunction.
	Zn: 10-45 g	Toxic to plants.

TABLE 6.12 (Cont.)

Category	Material/Quantity	Environmental or Health Effects
Gaseous emissions from refining	NO_x: 0.270 kg	Damages plants; aggravates asthma and other respiratory problems; increases development of chronic lung injury and diseases.
	SO_2: 0.717 kg	Corrodes stone and metals; damages plants; increases asthma, other respiratory problems; increases mortality among elderly, young, and individuals with preexisting respiratory diseases.
	VOC: 0.187 kg	Contributes to lung and other cancers and respiratory problems; contributes to ozone and smog production.
Particulate emissions from refining	BF: 580 g	Contains lead, manganese, zinc, other elements.
	BOF: 7-30 kg	Contains iron, iron oxide, other elements.
Energy use	21-35 GJ	Causes SO_2 and other emissions from fuel combustion; increases land, air, water impacts from coal and uranium mining, petroleum extraction, and power generation; creates worker accidents and public health risks; causes cancers.
Mining health effects	Fatalities: 2×10^{-7} Injuries: 1.3×10^{-5}	Includes death, loss of consciousness, restriction of work or motion, inability to perform all job duties.
Refining health effects (blast furnace)	Fatalities and injuries: 1.4×10^{-4}	Includes death, loss of consciousness, restriction of work or motion, inability to perform all job duties.
Foundry health effects	Fatalities and injuries: 1.5×10^{-4}	Includes death, loss of consciousness, restriction of work or motion, inability to perform all job duties.

See next page for footnotes.

TABLE 6.12 (Cont.)

[a] Computed on basis of a 2.5:1.0 ratio for iron ore to pig iron. Because steel produced from iron ore has approximately 25% scrap input, the 2.5 units of ore were multiplied by 0.75.

[b] Blast furnace.

[c] Basic oxygen furnace.

[d] The low end of the range of emission estimates represents the more efficient combinations of production technology and pollution control and raw material inputs with the lowest concentrations of contaminants, while the high end represents the least efficient processes and highest contaminant concentrations.

Sources: Bhatti (1992); Dehmel (1992); Elsworth (1984); Friberg (1986); Graham (1990); Kohout et al. (1990); Nriagu and Pacyna (1988); OECD (1991); Rogich (1992); Steiner (1976, 1993a,b); U.S. Department of Labor (1989, 1991); Young (1992a).

TABLE 6.13 Quantifiable Discharges and Impacts of Copper Production per Ton of Copper Produced

Category	Material/Quantity	Environmental and Health Impacts
Resource requirement	Ore: 99-99.5 t	Creates tailings; acid mine drainage releases heavy metals and toxins; disturbs and pollutes land, air, water, natural habitats; results in worker accidents, health risks.
Residual slag	2-4 t	Creates substantial waste for landfills or degrades landscape.
Sulfuric acid	2.0-3.4 t	Volatile; causes chemical burns; hazardous to upper respiratory tract, mucous membranes, teeth.
Heavy metal air emissions from smelting and refining[a,b]	As: 1,000-1,500 g	Causes skin abnormalities, skin and lung cancers, lung dysfunction, neurological disorders, hematological effects (including anaemia).
	Cd: 200-400 g	Causes hypertension, sterility, testicular hemorrhage, renal dysfunction, kidney damage, fibrosis, hypertension, pulmonary disorders such as emphysema; suspected carcinogen (lung and prostate).
	Cu: 1,700-3,600 g	Causes respiratory irritation.
	Pb: 1,300-2,600 g	Causes neurological and urinary tract disorders, anemia, reproductive and respiratory dysfunctions, hearing loss, liver, kidney, and bone damage, learning disabilities in children, cardiovascular disorders, blood abnormalities.
	Mn: 100-500 g	Toxic to infants; causes metabolic and intestinal problems, abnormalities and suppressed growth in plants and animals.
	Ni: 900 g	Causes pulmonary and immunological disorders, nasal and lung cancer, birth defects and malformations.
	Se: 50-150 g	Causes neurological disorders, hair loss, respiratory dysfunction.
	V: 5-10 g	Causes respiratory distress, neurological dysfunction.
	Zn: 500-1000 g	Toxic to plants.
Gaseous emissions from refining	NO_x: 0.967 kg	Damages plants; aggravates asthma, other respiratory problems; increases development of chronic lung injury and diseases.
	SO_2: 205 kg	Corrodes stone and metals; damages plants; increases asthma, other respiratory problems; increases mortality among elderly, young, and individuals with preexisting respiratory diseases.

TABLE 6.13 (Cont.)

Category	Material/Quantity	Environmental and Health Impacts
Energy use	94-98 GJ	Causes SO_2 and other emissions from fuel combustion; increases land, air, water impacts from coal and uranium mining, petroleum extraction, and power generation; creates worker accidents, public health risks; causes cancers.
Mining health effects	Fatalities: 3.1×10^{-6} Injuries: 1.7×10^{-4}	Includes death, loss of consciousness, restriction of work or motion, inability to perform all job duties.
Refining health effects	Fatalities and injuries: 3.7×10^{-4}	Includes death, loss of consciousness, restriction of work or motion, inability to perform all job duties.

[a] Data in this group are for copper and nickel production.

[b] The low end of the range of emission estimates represents the more efficient combinations of production technology and pollution control and raw material inputs with the lowest concentrations of contaminants. The high end represents the least efficient processes and highest contaminant concentrations.

Sources: Bhatti (1992); Castle (1989); Davenport (1993); Elsworth (1984); Friberg (1986); Graham (1990); Jolly (1993); Kohout et al. (1990); Nriagu and Pacyna (1988); OECD (1991); Rogich (1992); U.S. Department of Labor (1989, 1991); Young (1992a).

TABLE 6.14 Quantifiable Discharges and Impacts of Aluminum Production per Ton of Aluminum Produced

Category	Material/Quantity	Environmental or Health Impacts
Resource requirement	Ore: 4 t	Creates tailings; acid mine drainage releases heavy metals, toxins; disturbs and pollutes land, air, water, natural habitats; results in worker accidents, health risks.
Bauxite residue	2 t	Results in caustic solid waste for landfill.
Gaseous emissions from refining	NO_x: 0.608 kg	Damages plants; aggravates asthma and other respiratory problems; increases development of chronic lung injury and diseases.
	SO_2: 16.5 kg	Corrodes stone and metals; damages plants; increases asthma, and other respiratory problems; increases mortality among elderly, young, and individuals with pre-existing respiratory diseases.
	VOC: 0.101 kg	Contributes to lung and other cancers, respiratory problems; contributes to ozone and smog production.
	Fluoride: 0.5-1.0 kg	Damages vegetation; toxic to animals; causes eye and skin irritation, inflammation of the respiratory tract, breathing difficulty.
Energy requirements	133-174 GJ	Causes SO_2 and other emissions from fuel combustion; increases land, air, water impacts from coal and uranium mining, petroleum extraction, and power generation; creates worker accidents and public health risks; causes cancers.
Refining health effects	Fatalities and injuries: 5.7×10^{-4}	Includes death, loss of consciousness, restriction of work or motion, inability to perform all job duties.

Sources: Bhatti (1992); Carwile (1993); Castle (1989); Elsworth (1984); Friberg (1986); Graham (1990); Kohout et al. (1990); Koren (1991); McCawley and Baumgardner (1985); Nriagu and Pacyna (1988); OECD (1991); Rogich (1992); U.S. Department of Labor (1991); Young (1992a).

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7 SOCIAL AND POLITICAL CONTEXT OF RADIOACTIVE SCRAP METAL RECYCLING

This section assesses the context within which recycling of radioactive scrap metal (RSM) would occur and identifies cultural and institutional factors that are most likely to be relevant to the acceptability of RSM recycling. Regulation of radioactivity in consumer products is discussed in Section 7.1, followed in Section 7.2 by an overview of liability issues that may affect firms' decisions regarding participation in RSM recycling.

Cross-cultural studies of public attitudes toward radioactive substances are reviewed in Section 7.3 to determine commonalities and differences in public acceptance of nuclear-related risks and, especially, of radioactivity in consumer products. This information provides the basis for identifying the characteristics of RSM that are most likely to influence the acceptability of recycling. Findings from a survey of key organizations regarding their positions on nuclear risks and RSM recycling are presented in Section 7.4.

The purpose of Section 7 is to characterize the social, institutional, and political factors that are likely to affect decisions regarding RSM recycling. Where such factors may constitute barriers to scrap metal recycling, the goal is to identify possible remedies that would reduce or eliminate these obstacles. The key factors and some potential remedies are discussed in Section 7.5.

7.1 REGULATORY PRINCIPLES RELATED TO RADIOACTIVITY IN CONSUMER PRODUCTS

Recycling of RSM into unrestricted uses will result in some increase in residual radioactivity in metal products that are readily accessible to the general population. Radioactive materials are presently accepted and used by the public virtually throughout the world, with varying degrees of public recognition of the associated risks. Radioactivity is incorporated intentionally, for its beneficial properties, in a variety of medical products, household products, and personal items. It also occurs naturally in some consumer products or can be an unintentional by-product of beneficial functions of products. Common radiation sources involved in consumer products and associated dose levels are presented in Appendix E and are summarized here. In addition to intentional use of radioactivity, an unknown number of cases have occurred in which products have been accidentally contaminated with radioactivity before distribution. These situations are generally judged unacceptable, and when contaminated products are identified, they typically are removed from public use.

Radioactive materials are used routinely for medical diagnosis and treatment. Within this context, effort is made to limit exposures to the minimum efficacious dose. As suitable nonradioactive substitutes become available, the use of radioactive substances is generally curtailed. For instance, fetal risks have been reduced by substituting ultrasound for X-ray examinations (NCRP 1987). Also, when heart pacemakers were first developed,

they were powered by radioactive source material, but the development of long-lasting nonnuclear batteries ended use of such material.

Numerous household and office products currently in use in industrialized countries produce some exposure to radioactivity. Some of these items (such as smoke detectors, fluorescent lamp starters, and gas lantern mantles) may be recognized by the public as containing a radioactive component. Other common exposure sources are probably not recognized by the public as radioactive. These other sources include such common items as appliance indicator lights and electric blanket thermostats. In addition, natural gas cooking ranges and domestic water supplies cause radon exposures, and mineral-based building materials may contain uranium, thorium, and potassium isotopes. Granite, which is commonly used in constructing public buildings in the U.S.A. and Europe, is one of the major sources of radiation exposure for building occupants. In addition, the public is exposed to products that, although they do not contain radioactivity, do produce X-rays as a by-product of operation. Both color television screens and video display terminals are in this category.

Radiation exposures also result from activities outside of the home or office. For instance, the X-rays used in airport luggage inspection systems cause slight exposures of some members of the public. Also, phosphate fertilizers used in both home gardens and commercial agriculture generally contain radioactive potassium, as well as naturally occurring uranium and thorium. While there is some public awareness of the X-ray output of luggage scanning devices (since they are usually clearly marked), there is little awareness of the radioactivity of commonly used fertilizers.

Possession, distribution, and disposal of all of these radiation-emitting products are exempt from government regulation because of their conformance with the principles of dose limitation discussed below.

7.1.1 Regulatory Framework Affecting the Exemption Process

The dose limitation principles endorsed by the International Atomic Energy Agency (IAEA) — justification of practice, optimization of protection, and limitation of individual risk — are adhered to by countries regardless of their regulatory structure or exemption process for consumer products containing radioactivity. Differences in the implementation of these principles, however, can result in disparate exemptions from country to country. Variation in social utility of products among countries may account for some differences of opinion among different cultures regarding exemptible products. Differences in regulatory frameworks among countries can also lead to these differences.

Regulatory processes can be relatively open or relatively closed. Open processes allow for extensive public participation through comment periods, give consideration to the public's comments, and encourage consultation and consensus development among domestic and international governmental entities. The disadvantage of an open system is the time and resources it demands; the advantage is greater probable acceptability of the exempted product because of public participation in the exemption process. Closed systems may reach exemption decisions more quickly because of limited participation. If the public has

confidence in the regulatory process and the regulators, exemption decisions will probably be considered credible regardless of the closed nature of the process.

Regulators can make exemption decisions on a case-by-case basis or, additionally, by establishing a "de minimis" dose level for consumer products with radiation. A de minimis level is a low exposure level selected because the corresponding risk is generally considered trivial in comparison with other risks that the public typically accepts (Vance 1989). Consumer products containing radiation below the de minimis level would not require consideration for exemption because they are excluded from the universe of radiation sources subject to regulation. Products with radiation doses above the de minimis level would be subject to a case-by-case evaluation.

7.1.2 Dose Limitation Principles Underlying the Exemption Process

Exemptions to the normal system of notification, registration, and licensing required for products containing radiation are based on the principles of justification of practice, optimization of protection, and limitation of individual risk. These principles have been endorsed by the IAEA and the Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD/NEA).

Justification of practice means that deliberate public exposure to ionizing radiation in a specified usage is acceptable only if the exposure produces a positive net benefit. One factor that may justify a practice is the lack of other reasonable alternatives to the inclusion or use of the ionizing radiation. Justification of practice is the most elementary of the dose limitation principles (Webb 1989). If no positive net benefit arises from the practice or if an alternative to use of radioactive material exists, the practice will not be further considered for exemption.

Because the justification decision is based on perceived positive net benefit, it must reflect political, social, and economic values regarding what brings benefit to the society being protected. Production of a radiation-emitting item, even with a technically proven low dose, generally has not been deemed justified if the product has no, or very limited, social utility. Thus, smoke detectors are exempt; irradiated gem stones generally are not.

Optimization requires that doses resulting from the product be reduced to a level that is "as low as reasonably achievable" (the ALARA principle). Economic and social factors and the cost of any regulatory controls are included in determining what dose level is reasonably achievable. A product that cannot be made safer through reasonable regulatory controls is a candidate for exemption.

Individual risk levels are usually limited by controlling the doses received by the maximally exposed group. Regulators attempt to keep the annual individual dose to members of the high-risk group sufficiently low so that cumulative exposures from multiple exempted sources or practices will not exceed the annual maximum individual dose limit.

7.1.3 Regulatory Requirements

A consumer product that has been exempted from the normal regulatory requirements may still be subject to some controls. Regulators may require product advertising or labeling to include explanatory information about the presence of radiation in the product. Although the product may be free from other requirements, the manufacturer may be subject to regulation involving production processes, worker health and safety, minimization of secondary waste streams, monitoring and sampling protocols to ensure that approved product radiation levels are not exceeded, and record keeping and reporting requirements.

7.2 LIABILITY ISSUES

Those engaged in the enterprise of RSM recycling will face a number of legal constraints; among them are compliance with domestic and foreign regulations relating to the handling of RSM and to health and safety in the work place, compliance with domestic and foreign environmental regulations, and compliance with trade restrictions and international agreements relating to radioactive materials and the transportation of hazardous materials. Apart from these concerns, parties involved in the RSM industry must consider the possibility that persons could be injured by exposure to radiation from products made from RSM if, for some reason, the system limiting exposures to prescribed levels should fail. Processors and manufacturers, both in the U.S.A. and abroad, could be held liable for these injuries.

Many parties could be involved in bringing RSM from the source or storage heap to the consumer, and these parties could be located in any country. In addition, a person injured by RSM radiation could be located in any country — not necessarily the same country as any of the responsible parties. As a result, it will be necessary to consider the substantive and procedural law of all potentially involved countries and the applicability of international agreements to potential liability related to RSM recycling. Thus, international trade in recycled RSM presents a number of domestic and international legal issues that may be considered obstacles by potential participants in the industry.

That area of law relating to injuries caused by defective products is known as "products liability" law. Whenever an injury to an individual is allegedly caused by the condition of a product, that individual may have a claim against the party who designed, manufactured, sold, or furnished the defective product. Product liability issues are discussed in Section 7.2.1 for the U.S.A. and Section 7.2.2 for other countries.

7.2.1 Strict Liability in Tort — U.S.A. Law

The dominant element of products liability law in the context of RSM recycling is the theory of strict liability in tort. Under the common law, this doctrine imposes liability on individuals, regardless of fault and of precautions taken, for injuries caused by

"ultrahazardous"[1] or "abnormally dangerous"[2] activities. In the absence of specific legal precedent, it is uncertain whether RSM recycling might be considered an ultrahazardous or abnormally dangerous activity. A detailed comparison of the potential hazards of RSM recycling and those of other activities to which strict liability has been applied would be needed to determine the likelihood that a court would apply strict liability to RSM recycling.[3] However, the types of activities to which strict liability has been applied are generally orders of magnitude more hazardous than RSM recycling.

This doctrine imposes liability on a party or parties, regardless of fault, once a "defect" in the product is established as the cause of the injury, provided the product has left the control of the parties on whom liability is to be imposed.[4] Three ways exist by which a product can be defective: (1) the defect could be in the design, (2) the defect could be in the production or manufacture, and (3) the defect could be in a failure to warn or to provide adequate directions.[5] Each of the parties could be a defendant in a products liability suit because anyone "engaged in the business" of dealing in the product is a possible defendant.[6] This view of strict products liability has been adopted by at least 40 states in the U.S.A. and is codified in the Restatement (Second) of Torts (Section 402A: Special Liability of Seller of Product for Physical Harm to User or Consumer) which provides:

> (1) One who sells any product in a defective condition unreasonably dangerous to the user or consumer or to his property is subject to

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[1] Restatement of Torts § 519 (1938).

[2] Restatement of Torts § 519 (1977).

[3] A strict liability standard has been applied by courts in the U.S.A. to the following "abnormally dangerous" activities: blasting, crop dusting, the storage of explosives, the storage of certain quantities of inflammable liquids in an urban area, hazardous waste disposal, pile driving, and the handling of poisonous gases. *See* W.L. Prosser, J.W. Wade, and V.E. Schwartz, Cases and Materials on Torts 685-687 (8th Ed. 1988) and the cases cited therein.

A particularly significant application of the strict liability doctrine has been witnessed, in recent years, in the area of environmental torts. *See, e.g.*, Sterling v. Velsicol Chem Corp., 647 F. Supp. 303 (W.D. Tenn. 1986) (chemical company strictly liable to neighbors for personal injuries and property damage resulting from inherently and abnormally dangerous activities in operating a hazardous waste dump). Generally cases arise from personal injuries that are caused by toxic substances in the environment, including groundwater contamination, airborne contamination (e.g., nuclear test fallout), pesticide exposure, and hazardous waste exposure. For a thorough discussion of environmental torts and the role of strict liability in such cases, *see* Brennan, *Environmental Torts*, 46 Vanderbilt L. Rev. 1, 58-61 (1993).

[4] W. Freedman, International Products Liability § 1.17 at 55 (1987 & 1990 Supp.).

[5] For a thorough discussion of possible defects *see* M. Shapo, The Law of Products Liability § 8 (1990).

[6] *See* Restatement (Second) of Torts § 402(A)(1)(a) (1965).

liability for physical harm thereby caused to the ultimate user or consumer, or to his property, if

(a) seller is engaged in the business of selling a product, and

(b) it is expected to and does reach the user or consumer without substantial change in the condition in which it is sold.

(2) The rule stated in subsection (1) applies although

(a) the seller has exercised all possible care in the preparation and sale of his product, and

(b) the user or consumer has not bought the product from or entered into any contractual arrangement with the seller.[7]

Under the strict products liability standard, the product that caused the injury will be deemed to be "unreasonably dangerous" if it is "defective."

A number of defenses are available to a defendant in a products liability suit. The two most important defenses focus on the conduct of the plaintiff. A party may not be liable if (1) the plaintiff used the product despite being aware of potential dangers (assumption of risk) or (2) the plaintiff used the product in a manner that was not foreseeable to the manufacturer (misuse). Similarly, an effective disclaimer or an effective product recall may protect the defendant from liability. If the defendant is the government or a quasi-governmental entity such as a utility, a number of defenses may apply, including sovereign immunity,[8] the act-of-state doctrine, and the government contractor defense. The availability of any or all of these defenses will depend on the case and the jurisdiction in which it is brought.

All of the traditional tort remedies are available in a products liability context.[9] All compensatory damages are available, including pain and suffering, emotional distress, and loss of consortium. Damages for loss of profits, a contract remedy, may also be available. Perhaps the most important remedy available in a products liability suit is punitive damages, a remedy based on a public policy of deterring similar future conduct. This remedy often accounts for large judgments in the U.S.A. Attorneys fees may also be available for

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7 Restatement (Second) of Torts § 402(A) (1965).

8 A sovereign government is generally thought to be immune from suit unless it consents to the suit. *See* The Federalist No. 81, at 508 (A. Hamilton) (H. Lodge, ed., 1908). In the U.S.A., the Federal Tort Claims Act, 28 U.S.C. § 1346(b), 2671-2680, establishes the general circumstances under which the federal government has consented to suit. However, this waiver of sovereign immunity is limited by 13 exceptions.

9 *See* generally Prosser, Wade, and Schwartz, *supra* note 3.

successful plaintiffs. The availability of any or all of these remedies will depend on the case and the jurisdiction in which it is brought.

7.2.2 Products Liability in Other Countries

It has long been argued that differences between the product liability system in the U.S.A., with its no-fault, strict liability standard, and the products liability systems of Europe, Asia, Africa, and Latin America result in higher products liability and insurance costs for U.S.A. manufacturers and give a competitive edge to non-U.S.A. manufacturers.[10] However, a growing movement toward consumer protection outside the U.S.A. is expanding the role of products liability in the jurisprudence of many countries. The international trend toward consumer protection and the adoption of products liability norms comparable to those of the U.S.A. can, perhaps, best be seen by the products liability directive adopted by the European Economic Community (EC) in 1985.[11] That this directive is meant to bring European products liability standards closer to those of the U.S.A. is demonstrated by the adoption of the strict liability doctrine in products liability cases.[12,13]

The growth of international trade and the proliferation of multinational corporations has made companies and consumers around the world aware of the dangers of using products that have traveled internationally.[14] The ease with which merchandise and people can travel across borders also creates a number of legal difficulties. For instance, what is considered a sound manufacturing process in one country may be considered negligent in another. Or,

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[10] Stayin, *The U.S. Product Liability System: A Competitive Advantage to Foreign Manufacturers*, 14 Canada-United States L. J. 193 (1988).

[11] *Council Directive of 25 July 1985 on the Approximation of Laws, Regulations, and Administrative Provisions of Member States Concerning Liability for Defective Products (Directive)*, 28 O.J. Eur. Comm. (No. L 210) 29 (1985).

[12] But *see* Stiefel, *Resolution of International Products Liability Disputes: An Emerging Procedural Framework*, 16 Brooklyn J. Int'l L. 267 (1990) (arguing that, even if the directive is implemented, the EC products liability system will not change drastically and, certainly, will not follow the U.S.A. procedure).

[13] Like all EC directives, this directive cannot come into force until it has been implemented within each state's national legislation. As of 1990, Belgium, France, Ireland, the Netherlands, Portugal and Spain had not yet implemented the directive. Stiefel, *Resolution of International Products Liability Disputes: An Emerging Procedural Framework*, 16 Brooklyn J. Int'l L. 267, 269 (1990). For a thorough discussion of the provisions of the EC Directive and its possible effects *see id.* Havemann, *The EC Directive on Product Liability: Its Background, Aims and System* in R. Hulsenbek and D. Campbell, *Product Liability: Prevention Practice and Process in Europe and the United States* 17-30 (1989); Note, *Products Liability: A Comparison of U.S. and EEC Approaches*, 13 Syracuse J. Int'l L. and Com. 155, 174 (1986).

[14] Freedman, *supra* note 4, § 4.01 at 206.

what may be outside the parameters of strict liability in one country may be within the parameters of strict liability in another.[15]

Despite some movement of many of the world's nations toward the U.S.A. standard in products liability, a number of differences in the legal systems of other countries are likely to be maintained.[16] First, it is unlikely that a products liability case in another country could result in the types of enormous judgments seen regularly in the U.S.A. because neither pain and suffering[17] nor punitive damages are cognizable in most countries, and juries are not used in civil trials.[18]

Second, other legal systems do not possess the incentives to litigate that are inherent in the U.S.A. system. To begin with, contingent fees for lawyers are not allowed in many countries. In fact, plaintiffs in many countries are required to pay the defendant's attorney fee, in addition to their own, if they lose their products liability suit.

Third, and finally, procedural elements also discourage products liability cases. Pre-trial discovery is much more limited elsewhere than in the U.S.A., and it is more difficult to obtain statistical and technical data in many countries. Furthermore, class action suits are not permitted under the civil procedure of many countries.[19]

On the basis of these factors, products liability is not as substantial a disincentive to RSM recycling in many jurisdictions outside of the U.S.A. The prevailing perception among products liability scholars is that the peculiarities of the U.S.A. system of jurisprudence accommodate the enormous damage awards that manufacturers and vendors dread.[20] Thus, the threat of a large judgment is substantially less in most other countries.

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[15] *See* R. Hulsenbek and D. Cambell, *Product Liability: Prevention Practice and Process in Europe and the United States* 1 (1989).

[16] These conclusions are based on a study of nations in Europe and Japan. *See* Stayin, *The U.S. Product Liability System: A Competitive Advantage to Foreign Manufacturers*, 14 Canada-United States L. Jrnl. 193, 193 (1988).

[17] In some countries where pain and suffering is recognized, the amount of the award is limited by statute. This is not the case in the U.S.A. See generally, Freedman, *supra* note 4.

[18] The study found that civil jury trials were only found in Ireland with, on average, damage awards four to six times higher than in England, where juries are not used for civil trials. It is also suggested that awards determined by judges, rather that juries, are less emotional, not based on sympathy, and unaffected by the "deep pocket syndrome."

[19] *See* W. Freedman, *International Products Liability* § 6-11 (1987 & 1990 Supp.). *See* also W. Freedman, *Products Liability: An International Manual of Practice* (1990), wherein the author provides a comprehensive analysis of the substantive and procedural law of products liability in 28 countries.

[20] *See* W. Freedman *supra* note 4.

Because an RSM products liability suit could be brought in any country and involve parties of any nationality, the likelihood of success of such a suit would depend on a number of complex legal factors. These important factors, which are beyond the current scope of this report, include jurisdiction, *forum non conveniens* (the inconvenient forum),[21] discovery and the taking of evidence abroad, the applicability of international conventions and agreements, choice of law issues, immunity, and the recognition and enforcement of foreign judgments.

Another issue worthy of mention is the possibility that international standards may be developed that could affect eventual determinations of liability. If international standards relating to levels of radiation or manufacturing guidelines were developed and adhered to by parties involved in RSM recycling, those parties might be able to present a successful defense to liability in nonstrict liability jurisdictions. However, if strict products liability applies, then compliance with international standards would not act as a complete defense, but would merely serve as evidence that the design or manufacture of the product was not defective. Finally, the possibility always exists that an international agreement could be concluded that would limit or bar the liability of parties involved in the RSM recycling industry.

7.3 ASSESSMENT OF RECYCLING ACCEPTABILITY TO THE PUBLIC

This section compares attitudes and behavior related to risk perception in Asia, Europe, and North America with the goal of identifying cultural and risk characteristics that affect risk acceptability. Although the specific interest is in public perceptions of radioactivity in consumer products, that issue has not been the focus of any studies, but has only been addressed peripherally. Therefore, likely public responses to RSM recycling are inferred, in part, from more general studies of risk perception and acceptability of nuclear technologies and related activities.

7.3.1 Cultural Context of Risk Perception and Risk Acceptability

The perception of risk takes place within a cultural context that is affected by individual and societal values, the availability of risk information, the nature of personal experience with risks, and characteristics of the physical environment. Thus, the perception of risk associated with any particular hazard is likely to differ among countries and also to vary within countries, especially countries with relatively heterogeneous populations and conditions. This section first discusses the main characteristics of hazards that appear to determine risk perception and risk acceptability. That discussion is followed with information on the cultural determinants of preferences for societal risk taking (e.g., such as a decisions to recycle or to dispose of RSM).

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[21] For a discussion of how courts in the U.S.A. have used this doctrine to bar foreign plaintiffs in product liability actions *see* Miller, Forum Non Conveniens *and State Control of Foreign Plaintiff Access in U.S. Courts in International Tort Action*, 58 Univ. Chi. L. Rev. 1369 (1991).

7.3.1.1 Factors Affecting Risk Perception

An objective of many studies has been to identify the specific characteristics of hazards that elicit a perception of risk on the part of the general public. This process first requires defining what is meant by "risk." Some measure of the probability of individual fatality is a common operational definition of "risk." Researchers, employing a variety of approaches in empirical studies, found that measures of "voluntariness of risk assumption," of "disaster potential," and of "benefit" are important in explaining risk perceptions.

From a comparative study of German and American (U.S.A.) students, Von Winterfeldt et al. (1981) concluded that perceptions of risk depend primarily on people's judgments of individual fatality probabilities. The total number of potential fatalities affects risk perceptions only for those activities with a high level of disaster potential. In this risk rating exercise, the perceptions of the Germans and Americans were quite similar and were consistent with the relative ranking of risks based on reported fatality rates.

A study of health-related risks conducted in England showed that people's perceptions of an activity's risk and benefit are largely independent of each other (Harding and Eiser 1984). While perceived risk levels were found to be lower for some activities with relatively high levels of perceived benefits, other factors (such as the probability of the hazardous event's actually occurring and the probability of fatalities if the event were to occur) influenced risk perception. Individual respondents' characteristics, including gender and knowledge base, also influenced risk perception, as they have in other studies.

From its beginnings, scientific research on factors influencing risk acceptability has focused on public evaluation of the benefits of hazardous activities and the degree of voluntariness of individual participation in risk exposure. On the basis of analysis of U.S.A. governmental decisions, Starr (1969) concluded that the acceptability to society of a given risk level increases with the benefits of the activity, that it is greater when participation is voluntary, and that it decreases as the number of persons exposed to the risk increases. Analyzing survey responses, Fischoff et al. (1979) also found that higher risk levels are acceptable if they are associated with greater benefits. Risk acceptability was also greater overall for voluntary activity participation. These basic findings have been confirmed by most of the extensive research on factors affecting risk acceptability that has followed.

7.3.1.2 Cultural Patterns Linked to Variation in Risk-Related Attitudes

Since about 1980, exploration of the cultural, historical, and political context of risk perception has been increasing. This research has focused on cultural patterns that are systematically linked to various issues, including perception of technological risks. On the basis of previous research, Dake (1991) related three major types of individual worldviews to respondents' concern with a broad range of contemporary issues, among them: "dangers associated with nuclear energy," "environmental pollution," and "dangers associated with technology." The three types of worldviews of interest are the hierarchical, individualist, and

egalitarian. Respect for authority characterizes the hierarchical worldview, while the individualist is free-market oriented and supporting of self regulation. Egalitarians reject authority and espouse an equal sharing of an earth seen as fragile and finite.

Dake (1991) found distinctive patterns of concern with different types of issues, depending on whether individuals were characterized by a hierarchical, individualistic, or egalitarian worldview. For the hierarchical and individualistic worldviews, levels of concern with perceived dangers of nuclear energy, pollution, and technology were low. For egalitarianism, in contrast, the levels of concern were moderately strong, especially relative to concern with other issues included in the survey. These findings imply that acceptance of risks associated with nuclear power, environmental pollution, and technology will be greater in societies oriented toward hierarchical social relations or individual self-determination than in societies with a strong egalitarian worldview.

7.3.2 Cross-Cultural Comparison of Attitudes toward Radioactivity

Because risk perception is culturally determined, differences in attitudes toward risk taking and toward the distribution of risk within society are to be expected among countries. These attitudes are affected by environment, experience, and education, both formal and informal. Countering the forces that create differences in risk perception, however, is the increasing worldwide influence of the media and the flow of information across national boundaries. Because of the need for cross-cultural communication regarding risks, several studies have been conducted to examine the cognitive structures involved in risk evaluation.

Table 7.1 presents key findings of five different studies that employed the same methodology and basic questionnaire to assess risk perception by persons from different cultures. The original study was conducted by Slovic et al. in the U.S.A. in 1979 (and was replicated there in 1987). A comparable study in Hungary was reported by Englander et al. (1986), and results for a similar study in Norway are compared to the previous studies by Teigen et al. (1988). In addition, a similar study was conducted in France (Karpowicz-Lazreg and Mullet 1993), and a study using a subset of hazards from the original questionnaire was conducted in Hong Kong by Keown (1989).

In each study, college students were asked to rate a set of hazards according to the risk of dying faced by members of society as a whole due to each hazard. The scale extended from 0 (not risky) to 100 (extremely risky). Comparable items from the studies are summarized here. The mean risk rating for each hazard, the relative ranking of the six hazards involving some form of radioactivity, and the overall mean rating for the 86 hazard types in these four studies are shown in Table 7.1. The mean level of riskiness over all of the rated activities is considerably higher for the U.S.A. and French samples than for the others. Within the data ranges, the U.S.A., French, and Hong Kongese ratings are relatively high for all of the hazards that involve some exposure to radioactivity. While this result indicates greater risk sensitivity in the U.S.A. and French populations and heightened perception of nuclear risks in particular, the risk rankings show a general consistency across

TABLE 7.1 Comparative Risk Ratings[a] and Rankings for Norwegian, American, Hungarian, French, and Hong Kongese Populations

	Norwegians		Americans		Hungarians		French		Hong Kongese	
Hazard	Rating	Rank	Rating	Rank	Rating	Rank	Rating	Rank	Rating	Rank[b]
Nuclear power	46.8	1	71.5	1	31.6	1	68.6	1	68	1
Radiation therapy	38.5	2	52.7	3	13.2	3	47.2	2	48	2
Chemical fertilizers	15.9	3	55.0	2	17.7	2	40.2	3	46	4
Sunbathing	15.7	4	19.7	6	11.0	4	32.3	5	27	5
Diagnostic X-rays	13.3	5	43.8	4	9.1	5	39.9	4	47	3
Fluorescent lights	11.8	6	21.5	5	8.0	6	22.6	6	–[c]	–
Mean risk (86 hazards)	27.2		39.7		20.9		40.4		NA[d]	

[a] Average rating based on a risk scale of 0 (not risky) to 100 (extremely risky).

[b] Rank out of a total of 30 hazards.

[c] No data.

[d] Not applicable.

Sources: Teigen et al. (1988); Karpowicz-Lazreg and Mullet (1993); Keown (1989).

all of the samples. Fluorescent lighting, in particular, appears to be viewed as presenting only minimal risks in all four countries where it was rated, in spite of the use of thorium in the starter mechanisms.

Factor analysis of the U.S.A. data by Slovic et al. (1985) identified two risk characteristics that, together, explained 75% of the variance in risk ratings. The first, designated "unknown risk," was associated with the hazard being unknown to those exposed, unknown to science, delayed in its effect, involuntary, and unfamiliar. The second, which the authors termed "dread risk," was associated with the perception of hazards as certain to be fatal, dreaded, and having catastrophic potential. Comparable analyses were conducted on data from each of the other study samples discussed above, except the French sample.

The Hungarian data (Englander et al. 1986) also showed evidence of two major factors influencing the perception of relative risks. These factors largely correspond to those found in the American study. Significant differences did, however, exist between the Hungarian and American studies in the apparent importance of some of the characteristics related to each factor. For instance, the Hungarians considered nuclear power to be high on the "dread" rating, but much less unknown than the Americans rated it. In general, the Hungarians sampled were less concerned about "high-tech" risks than the Americans and more concerned about risks from accidents, pregnancy and childbirth, poisonous mushrooms, and caffeine. Thus, there appear to be differences both in the importance of various characteristics of hazards and in the relative ranking of specific hazard risks between these populations.

Analysis of the Norwegian data showed a greater confidence in science, a perception of more risks as being familiar, and the hazard consequences as more delayed than the American data indicated. Factor analysis of the risk characteristics identified two major factors accounting for 74% of the variance in risk ratings. On the basis of their most strongly associated risk characteristic, these factors are called "fatal" risk and "involuntary" risk by the authors. While there is some commonality with the original factors developed by Slovic et al. (1985), the differences are greater than in the Hungarian study, and the primary focus in evaluating risks is clearly different.

Factor analysis of the data is not fully reported for the Hong Kong study, but, again, two main factors in risk perception were identified. The factor designated "unknown" risk was associated with involuntariness, delayed effect, and being unknown to those exposed. "Dread" risk was determined by catastrophic potential, dread, and certainty of fatality. While the same factor names are used as in the original American study, the association of involuntariness with "unknown" risks represents a difference in perception regarding risks.

Another study with a comparable methodology was conducted in 1988 by Kleinhesselink and Rosa (1991) among both American and Japanese students. In spite of the 10-year interval since the original (Slovic) study, the same factor structure was identified for the American student sample. The Japanese cognitive structure indicated by the factor analysis was similar, except that the characteristic of involuntariness carried less weight in determining the "dread" risk factor. Though the evaluative structure was comparable for the

two groups, substantial differences existed in the perception of risk associated with specific hazards. In regard to nuclear-related risks in particular, the Japanese viewed these risks as more familiar, and known to both individuals and to science.

This body of research demonstrates that major similarities exist in nuclear-related attitudes between relatively well-educated U.S.A. and Asian populations and between U.S.A. and European populations. The cognitive structures employed in evaluating risks are certainly comparable. However, numerous differences also exist among cultures in the relative ranking of specific societal risks. These differences appear to be mainly due to differences in the environmental and cultural context of the countries studied. In general, the relative ranking of various types of the subset of nuclear-related risks appears to be very similar.

A separate, and somewhat more complex, investigation of risk acceptability was conducted in the Netherlands by Vlek and Stallen (1981). They interviewed 673 subjects, representing both sexes, three age groups, and four categories of residential distance from Rotterdam Harbor, which has considerable heavy industrial activity. Respondents rated various aspects of 26 hazardous activities regarding their riskiness, beneficiality, and acceptability. Conceptions of riskiness, when no definition was provided by the interviewers, were found to depend on the magnitude of a potential accident and the degree of organized (i.e., regulatory) control. Considerable variation was noted in individual evaluations of the risk-related factors, with some consistency among population subgroups. For instance, risk ratings for "large-scale activities" increased with residential distance from the harbor, perhaps because those who perceived it as more risky located farther from it. The extent of individual variation in risk perception was such that Vlek and Stallen questioned the appropriateness of using any "average" measures. Individual scale values for beneficiality were found to correlate strongly with levels of acceptability, with riskiness apparently playing a secondary role in hazard acceptability.

7.3.3 Implications for Acceptability of Radioactive Scrap Metal Recycling

As discussed in the previous sections, both the characteristics of the hazard and the cultural context of risk perception affect societal decisions regarding risk acceptability. This section examines how RSM fits this framework.

7.3.3.1 Radioactive Scrap Metal Recycling Process Characteristics

In regard to public perception of risk, RSM recycling is at a disadvantage (compared with some other activities with equally low probability of causing harm) because of the stigma currently associated with nuclear weapons and nuclear power in most industrialized countries. This stigma has largely been avoided by the metals, petroleum, phosphate, and coal industries, all of which release substantial quantities of naturally occurring radionuclides

to the environment. Thus, development of a broadly based RSM recycling process may be more acceptable to the public than one that solely or primarily serves the nuclear industry.

It is unlikely that any direct benefit from including radionuclides in metal products will be perceived and, certainly, none has been claimed. This situation is a major drawback for public acceptance of RSM recycling because in virtually all existing uses of radioactivity in consumer products there is no adequate substitute for it. This factor has been one of the major premises for exempting such uses from regulation. In contrast, the main benefit of recycling RSM is the avoidance of environmental and health damages from replacing the metal. Since this benefit is an indirect one, it may render the recycling alternative less acceptable than if the benefit were direct.

Public acceptability of risk also depends on hazard characteristics, such as the probability of disaster and the voluntariness of participation in the activity leading to risk exposure. RSM recycling holds little potential for disaster because the levels of radioactivity involved would be very low and the radionuclides would primarily be bound into the metal. The resulting metal products would be as unlikely to cause a disaster as would the current global metal stock, which contains traces of naturally occurring uranium and thorium, traces of Co-60 from measurement devices used in steel production, and traces of fallout from nuclear weapons testing (Kuppers 1988). While disaster risks would be extremely low, assumption of the risks from metal exposure would be involuntary, as is the case for the present risks from radioactivity in metals. Unless the public is convinced that recycling is less risky than metal replacement, the involuntary nature of exposure is likely to cause public resistance to recycling.

7.3.3.2 Cultural Characteristics

The implications of the effects of cultural characteristics on risk acceptability are mixed in the case of RSM recycling. Recycling of RSM may be most acceptable in countries where a hierarchical worldview predominates, because of a greater tendency in such cultures to trust assurances of process safety and to accept decision making by regulatory agencies. Egalitarian-oriented cultures are likely to be more concerned about pollution and opposed to nuclear power, but they are also likely to see conservation of resources as desirable and to be sensitive to the issue of environmental and health impacts in less-developed countries from mining ores to replace RSM.

Regardless of the overall cultural orientation in a given country, there is substantial variation in attitudes among individuals, and antinuclear activist organizations exist in many industrialized countries. Among the strategies employed by antinuclear organizations have been opposition to any release of radioactivity, no matter how small, and opposition to any waste reprocessing or disposal alternatives that would increase the viability of nuclear power. Individuals who are committed to an antinuclear ideology are likely to oppose RSM recycling as a means of expressing their opposition to nuclear power. Given the nature of such opposition, information regarding the relative risks of recycling versus replacing the metal

resources is unlikely to influence antinuclear groups regarding the acceptability of RSM recycling.

In the U.S.A., a somewhat unique hindrance to RSM recycling acceptability exists because of the development in recent years of an attitude that the government should protect people from all risks. This "zero-risk" mentality is demonstrated in the demand for protection from pollutants, even at levels where initial statistical risks are negligible. This attitude is reflected in the detailed investigation of accidents to assess responsibility and to institute preventive measures, almost regardless of the cost. In such a cultural atmosphere of risk avoidance and denial of the pervasiveness of risk, the acceptability of RSM recycling is questionable.

7.4 RECYCLING ACCEPTABILITY TO STAKEHOLDER ORGANIZATIONS

The formal and informal positions of institutions and organizations with primary interests in the scrap metal market and in the political arena affecting RSM (hereafter referred to as "stakeholder organizations") are summarized in this section. An understanding of the basis for these positions and the degree to which such groups may be willing to consider risk and cost trade-offs between recycling and disposal will provide a basis for policy development. The information available for this evaluation is primarily for the U.S.A. Efforts made to solicit information from groups in other countries were not successful.

7.4.1 Identification of Stakeholder Organizations

As shown in Table 7.2, the stakeholder organizations involved in the issue of acceptability of recycling RSM include groups concerned with general environmental and specific nuclear safety issues; trade unions whose members would be physically involved in RSM recycling or in the production of goods containing RSM; and industry trade associations that represent nonnuclear industries involved in or affected by RSM recycling. These industry groups include the mining and metals industries and the oil and gas industry. Each of these various groups has a different position that reflects the specific interests and needs of that group's constituent members.

Environmental and related groups that have expressed opinions regarding RSM recycling are largely issue-oriented advocacy organizations that derive support from the general public. Also interested are the dozens of local environmental and antinuclear citizen groups that have been organized around specific site or regional pollution issues. These regional and local groups are diverse, numerous, and (generally) volunteer organizations. The regional and local groups were not surveyed as part of this study, although many of them interact with the U.S. Department of Energy regarding nuclear issues.

TABLE 7.2 Stakeholder Organizations Surveyed Regarding Radioactive Scrap Metal Recycling

Organization	Major Focus
Environmental Groups (5)[a]	General environmental advocacy Nuclear-specific interest groups
Trade Unions (laborers) (1)	Direct involvement in RSM recycling (handle RSM) Indirect contact with RSM (manufacture products)
Industry Trade Associations (5)	Metals and mining Scrap and recycling Oil and gas production

[a] Number of groups responding to survey questionnaires.

Several trade unions have a direct interest in RSM recycling issues. Workers involved in the smelting of iron and other metals, represented in the U.S.A. by the United Steelworkers, have a direct stake in RSM recycling because it may increase workplace risks, as well as create new job opportunities. The Oil, Chemical, and Atomic Workers Union has a stake because of the potential involvement of nuclear workers in RSM recycling. The Sheet Metal Workers Union is also actively involved in nuclear waste issues, with a functioning joint labor-management committee on hazardous and nuclear waste.

Industry representatives with a direct interest and role in RSM recycling include those directly involved in the smelting and manufacture of metals, such as the Aluminum Association and the Iron and Steel Institute, and the scrap and recycling industries represented by the Institute of Scrap Recycling Industries. Significant interest has also been voiced by the oil and gas industry, which has specific interests in recycling of drill pipe and other oil-field materials that become contaminated with naturally occurring radioactive materials (NORM). The phosphate mining industry has similar problems with NORM-contaminated equipment.

7.4.2 Survey of Positions of Stakeholder Organizations

To understand and compare the positions of these different groups, we identified and surveyed some representative organizations. The survey form, shown in Section F.1 of Appendix F, was designed and tested to encourage detailed responses to key questions, as well as to encourage expression of a full range of concerns related to RSM recycling. The survey solicited the following information:

1. Position on proposed U.S. Nuclear Regulatory Commission regulations designating radioactivity levels "below regulatory concern" (BRC),

2. Position on RSM recycling and the rationale for that position,

3. Major concerns with RSM recycling,

4. Position on trace radiation levels as a factor in supporting/opposing RSM recycling, and

5. Evaluation of the trade-offs between RSM recycling and disposal.

The groups' positions on these issues reflect a range of opinions, perceptions, and attitudes towards RSM recycling. Many of these responses are specific to each type of group and represent the types of concerns identified with the group's members or constituents. Groups that responded to the survey are listed in Section F.2 of Appendix F.

The positions of environmental groups on RSM recycling generally reflect skepticism about RSM recycling. Antinuclear groups constitute a core of opposition to all forms of RSM recycling, which they characterize as a form of deregulation of radioactive waste. At their extreme, these groups argue that "no level of ionizing radiation is safe." Several general environmental groups appear to take a somewhat more flexible position. While not stating its position on RSM recycling unequivocally, one recognized the need to set residual radioactivity standards for site cleanups and urged that the U.S. Environmental Protection Agency be given more authority to set and enforce such standards. Other general environmental organizations, although not of the stature of the national membership groups, also appear open-minded about RSM recycling, "provided that adequate safety standards are met."

In general, labor unions accept the need to recycle RSM and support some form of recycling "as a sound environmental approach." The trade unions could play an important role in supporting development of regulations for RSM recycling. While they have an overriding interest in ensuring worker safety, the unions also have an interest in job creation and market growth. Since RSM recycling represents a potential growth sector for some unions, they may favor of RSM recycling as long as it can be demonstrated that worker exposure is minimized. In a political context, the unions interested in this issue could provide important middle ground between the positions of environmental groups and those favoring RSM recycling in some form.

Industry trade associations and their individual members hold a broad range of positions on RSM recycling. On one extreme, the Aluminum Association strongly opposes RSM recycling and regularly advises its members to avoid all contaminated shipments. The Aluminum Association is concerned that RSM recycling will contaminate the recycling waste stream and also create confusion and fear on the part of consumers. However, at least one large member of the Aluminum Association has expressed conditional acceptance of RSM recycling, with a list of detailed concerns.

Nearly all other industry groups surveyed support some form of RSM recycling, although for varied reasons. The Iron and Steel Institute does not have a clear position on

RSM recycling, but states that "for certain product lines, some small amounts of low-level radioactive material may be acceptable." The most active industry group supporting some form of RSM recycling is the Institute of Scrap Recycling Industries. It is recommending new U.S. Nuclear Regulatory Commission regulations to permit the recycling of RSM, including, but not limited to, NORM-contaminated scrap. The oil industry also has strong interest in recycling of NORM-contaminated RSM. Some major petroleum companies with NORM-contaminated scrap problems are considering establishing large-scale oil-field smelting operations since the RSM is rejected when identified by monitoring systems at commercial smelters.

7.4.3 Major Concerns of Stakeholder Organizations

Each major organization's position on RSM recycling presented above is based upon specific concerns that reflect the interests of the group's members. These concerns can be divided into several categories: liability, control of health/safety risks, and other concerns. Clearly, however, several specific concerns identified below fall into more than one category. It is important to note that all of the concerns expressed would be addressed in the normal course of the regulatory process.

7.4.3.1 Liability Concerns

Concerns with liability were not as common as expected, possibly as a result of a general lack of attention given to the RSM recycling issue by major industry groups. One environmental group voiced concern about "abuses of unverifiable, irretrievable contamination," which may indicate a general concern for health risks, accountability, and liability issues.

7.4.3.2 Control of Health/Safety Risk Concerns

Nearly all respondents expressed concerns about health and safety risks associated with RSM recycling and agreed on the need to ensure adequate safety standards and controls. Environmental groups, especially the major opponents of BRC regulations, voiced strong concerns about "unnecessary exposures to unconsenting people," and "the damage to human health caused by exposure to radiation." From the perspective of these groups, environmental impacts associated with RSM recycling make it undesirable.

The Sheet Metal Workers expressed detailed concerns relating to worker health and safety, including the need for material documentation, worker training, safety inspections, and proper disposal of residuals. The Iron and Steel Institute also expressed concern about specific health and safety-related issues: contamination of metals for certain product uses that may result in human exposure; contamination of melt shop operations, need for pollution control facilities, and disposal/hauling problems; and introduction of more dangerous isotopes.

7.4.3.3 Oil Industry Concerns with Recycling of NORM-Contaminated Equipment

At least one major oil company with significant amounts of NORM-contaminated drill pipe has studied the issues and problems associated with RSM recycling in detail. Among the major findings presented by a recent oil-industry study (Dehmel et al. 1992) are the following:

- Given the evolving regulatory climate, oil industry practices have shifted away from conventional land disposal to decontamination and storage.
- A comprehensive recycling program is needed in order to convince the scrap recycling industry and regulatory agencies that recycling can be both viable and safe. Such a program must ensure the protection of the workers, general public, and the environment.
- Techniques to control radiation exposures in recycling processes are available and can be implemented.

7.4.3.4 Other Concerns

Several environmental groups and one industry group expressed concern that RSM recycling would harm conventional recycling programs by bringing confusion and fear into existing programs. One strongly antinuclear environmental group expressed concern over the impact of RSM recycling on economic competitiveness, although it is unclear what specific reasons motivate this concern. Finally, oil industry representatives and the Institute of Scrap Recycling Industries, two of the most informed supporters of RSM recycling, point to the need for a massive education and public relations campaign to improve public acceptance.

As a key participant in any RSM recycling scenario, the Institute of Scrap Recycling Industries in particular has expressed additional concerns regarding the problem of sealed radioactive sources entering the recycling stream and the associated costs of removal and disposal. The Institute is also concerned about NORM-contaminated scrap that is sufficiently radioactive to trigger radiation detection monitors but is unregulated in all but a few states. Concern was also expressed about the high cost of disposal under rules promulgated for higher levels of contamination.

7.4.4 Evaluation of Trade-Offs by Stakeholder Organizations

Several groups (including several industry trade associations and trade unions) recognized the benefits of RSM recycling compared with disposal and replacement. The Sheet Metal Workers' response was representative: "To the extent that recycling can be achieved while protecting human health and the environment, we support this approach. Disposal is a finite method with potential harm to health for many years if accidentally disturbed." One

group reserved judgment on the trade-off question, without knowing specific details of the alternatives.

The major exception is the strong resistance of environmental and antinuclear groups to any alternative that causes radiation exposure. Typical of this position are comments such as "The only good solution is to stop generating the hazardous substance. Pollution prevention is the only successful means of environmental protection," and "isolate the waste from the environment and people." A more moderate position, balanced the inherent benefits of recycling with health and safety concerns: "Because reuse of scrap would present greater potential for exposure, adequate safety data and standards would become more essential."

The survey results indicate that the trade-offs between recycling and disposal have not generally been recognized or understood by many of the key organizations. Because of the critical importance of alternatives to RSM recycling, a good starting point for future study and education may be this particular issue of trade-offs between proposed alternatives.

7.5 FACTORS AFFECTING SOCIAL AND POLITICAL IMPACTS OF RADIOACTIVE SCRAP METAL RECYCLING

This section identifies factors that may be major impediments or keys to the success of an RSM recycling initiative. Although countries have identified release criteria that allow for RSM recycling, the requisite assessment and decontamination techniques are practicable, and a supply of RSM is readily available (see Section 3), recycling of RSM is currently impeded. The barriers to recycling include dissimilar national criteria for release, unsuitability of RSM for some uses, potential costs of compliance with the regulatory structure associated with RSM recycling, and possible lack of public acceptance of RSM recycling.

7.5.1 Benefit and Risk Perceptions by Stakeholder Organizations and the Public

Affected sectors of society must evaluate the impacts of both RSM recycling and of RSM disposal and replacement in order for the recycling concept to gain sufficient momentum for action and public support. In the U.S.A., the petroleum and mining industries are beginning to press for standards for decontamination and recycling of pipe and equipment contaminated with NORM. The Institute of Scrap Recycling Industries is calling for a national determination of a safe level of contamination in scrap metal. The U.S. Department of Energy and the commercial nuclear power industry have realized the need to consider recycling as an alternative to burial of millions of tons of minimally contaminated scrap. The public has already demonstrated its interest in the concept of RSM recycling and is likely to be active in the debate. The involvement of these differing institutions indicates that the time may be opportune for a comprehensive review of RSM recycling.

In reaching an international consensus on RSM recycling, perceptions of the overall risks and benefits are of paramount importance. Public recognition that there are no "zero-risk" alternatives is essential. Process design and regulatory controls can be employed to keep such risks of recycling RSM to a very low level. Long-term storage and/or disposal of the RSM also presents risks, not only directly from those activities themselves, but also indirectly from the mining and smelting activities and energy production necessary to replace the discarded metal stock. These risks are considerably higher than the risks of recycling RSM. Indeed, avoidance of these risks and avoidance of the economic costs of producing replacement metal are the major benefits of the recycling option. Key organizations and the public must to be sufficiently informed about the alternatives to evaluate the risk/benefit trade-offs.

7.5.2 Detectability of Radiation in Scrap Inputs and Finished Products

People tend to be aware of and to try to avoid risks that give a clear signal of their impending occurrence. The public will accept RSM and products in which it is incorporated much more readily if the radioactivity level is sufficiently low that it does not set off standard radiation-detection alarms. In many industrialized countries, there are both fixed and mobile radiation detectors in scrap yards and a variety of other locations. As a result, numerous incidents have occurred around the world in which radiation has accidentally been discovered in metal scrap or metal products, with the discovery sometimes occurring after structural steel was incorporated in a building. Regardless of the country involved, these incidents have generally resulted in strong public demands for the government to find and remove all of the contaminated material. If the activity levels of RSM are high enough that the reused equipment or fabricated metal products trigger standard radiation detection systems, public acceptance of recycling will be unlikely. However, activity levels that are low enough to be protective of human health are unlikely to cause such alarms.

7.5.3 Public Confidence in Institutional Controls

When establishing release standards, regulators may base their decisions on the principle that the standard should correspond to the level at which individuals knowledgeable of the risk would not commit significant portions of their own resources to reduce the risk (Royal Society of London 1983). Or, they may define as a trivial dose one that is small in relation to the variation in naturally occurring background radiation (IAEA 1988). However sound these principles may be, regulators' assessments of risk may not be accepted by the public if those assessments do not relate to the way people perceive and evaluate risk.

For instance, in most Western countries, risk perception and risk acceptance are influenced, among other things, by the degree of voluntariness associated with the risk (Douglas and Wildavsky 1982). Thus, dosages that result from voluntary exposures, such as living at high altitude, will not necessarily be seen as comparable to involuntary risks, such as exposure to residual contamination in steel used in automobiles. Thus, aspects such as the involuntary nature of exposure to recycled RSM must be accounted for in establishing

institutional controls. This "accounting" is usually accomplished by limiting risks to lower levels than those considered acceptable for voluntary hazard exposure.

The potential for public acceptance of RSM recycling will be affected by the general level of public trust in the regulatory institutions involved and in the nature of information received from various sources. For instance, statements in support of RSM recycling by knowledgeable persons who are generally well regarded will tend to increase public acceptance. In contrast, contradictory statements regarding the risks presented by competing teams of "experts" will tend to create public uncertainty about the accuracy of the risk assessment and result in concern that the regulatory organizations cannot be trusted. Thus, public acceptance of RSM recycling is likely to be increased by a high degree of consensus in the scientific community on its desirability and by effective communication of the low level of public risk.

7.5.4 Nonuniformity of Release Standards among Countries

Several countries have established or are proposing criteria for restricted or unrestricted release of contaminated scrap. Differences among countries in these domestic release criteria may interfere with the unrestricted transboundary movement of scrap metal that normally occurs in the international scrap market. Nonuniformity of countries' criteria means that RSM that meets one country's release levels for general melting in ordinary steel furnaces with inactive scrap (for example, in Germany the specific overall activity of each item cannot exceed 1 Bq/g and the surface activity must not exceed 0.5 Bq/cm^2 [Neider 1992]) may not be accepted in other countries. This problem could make RSM recycling difficult and the market inefficient if the closest or most appropriate scrap use is in a neighboring country that does not allow RSM melting or has more restrictive release limits. End-use products made from recycled RSM may also be restricted to domestic use if the release standards vary. This restriction would occur if countries impose regulations that preclude the sale, transport, or use of products containing residual radioactive contamination other than that due to naturally occurring radiation.

Individual countries also regulate consumer products that contain radioactive substances or emit ionizing radiation. Although countries adhere to the principles of dose limitation — justification of a practice, optimization of radiation protection, and limitation of individual risk (IAEA 1988) — for the exemption of products from regulatory control, such adherence does not guarantee that all countries will reach compatible decisions regarding what products can be exempted. The cross-boundary movement of consumer products could be jeopardized by nonuniform exemption decisions.

The cost factors affecting RSM recycling include the economics of decontamination technologies, availability of decontamination and recycling facilities, market development, transportation systems, and management of secondary waste streams. The costs also include those of developing, implementing, monitoring, and complying with the regulations attendant to each activity associated with recycling. The costs of developing such a regulatory structure

will be high but not prohibitive. Many countries have already developed a similar structure to manage hazardous wastes.

It is the cost of compliance with the regulatory structure that could become a barrier to RSM recycling. If the compliance costs associated with recycling appear to be prohibitive to participants in the scrap metal market, there will be no incentive to accept RSM. While the regulatory structure must be based on standards that protect human health and the environment, the urge to establish release standards that are as low as possible may increase the costs associated with measuring and verifying achievement of release levels. For example, modifying release levels from 4 Bq/cm^2 to 0.4 Bq/cm^2 for beta-gamma and from 0.4 Bq/cm^2 to 0.04 Bq/cm^2 for alpha emitters can increase monitoring and verification costs by as much as 50% (OECD 1991). Significant monitoring and verification costs and associated record keeping may make RSM recycling unattractive to industry.

7.6 REFERENCES FOR SECTION 7

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APPENDIX A:

METHODOLOGY AND SUMMARY TABLES FOR POWER REACTOR REFERENCE PLANT DATA SETS

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METHODOLOGY AND SUMMARY TABLES FOR POWER REACTOR REFERENCE PLANT DATA SETS

A.1 INTRODUCTION

Appendix A documents the methods used to obtain the inventory parameters for nuclear power plants and presents the input data illustrating the application of the methodology. Descriptions of the categorizations of plants worldwide that were employed in deriving estimates of metal mass are contained in Section A.2. The tables that comprise Section A.3 present the listing of plant information and the metal mass values derived from the algorithms.

The quantities and types of metal scrap obtained from a dismantled reactor depend upon the class of reactor. Within each major reactor class, the amounts of material may also depend significantly upon a range of secondary characteristics, or identifiers, that are included in the plant input descriptor list. These identifiers includes country (effects of national differences in regulation), vendor (variations in design approach, such as the number of steam generators for a given power), architect-engineer (differences in balance-of-plant layout that affect the volume of concrete and mass of structural metals), period of construction (many extra systems were required after the Three Mile Island accident), number of steam turbines (combining smaller turbogenerator sets for a given power output requires more commodities), and cooling (the form of cooling water disposal or recycle, sea cooling or river cooling, and cooling towers of various designs, all require different amounts of commodities). The available databases are not sufficiently detailed to correlate all of these effects with the corresponding identifiers. If needed, however, additional correlations keyed to the existing identifiers can be added to the current spreadsheet methodology.

A.2 REFERENCE NUCLEAR POWER PLANT METHODOLOGY

A.2.1 Background

Reference plants of each reactor type were defined to form the basis for a range of simple algorithms that estimate waste-stream quantities from a minimum of input data. For each plant, the metal mass data are grouped into one of the four metal activity categories: (1) suspect radioactive, (2) surface-contaminated — removable, (3) surface-contaminated — fixed, and (4) activated, as defined in Table 3.1. The algorithms take into account the wide range of plant sizes and types. For pressurized water reactor (PWR) and boiling water reactor (BWR) plants, adjustments are made to account for differences in size. United Kingdom gas-cooled reactors (GCRs) include Magnox reactors and advanced gas-cooled reactors (AGRs). Former Soviet Union VVERs are divided into 440-MWe and 1,000-MWe

classes. This methodology is the basis for the annual increments in potential scrap metal inventories listed in Appendix B.

All metal masses for PWR and BWR plants are adjusted for design power levels scaled to the corresponding reference plant, on the basis that mass is proportional to the design electrical output to the 2/3 power ([design electrical power]$^{2/3}$). Because some plants have been derated, the electrical output values used are the original design power ratings. This scaling is based on PWR and BWR vessel mass data from *Nuclear Engineering International* (1991, 1993) and applies generally to the full range of vendors and countries. Although this scaling relationship has general validity, there is considerable scatter in the numerical multipliers, yielding vessel masses that tend to group by specific countries or vendors.

Published plant mass data show wide variations (Smith et al. 1978; Bryan and Dudley 1974; United Engineers and Constructors 1972; El-Bassioni 1980). The studies cited by El-Bassioni (1980) show estimated PWR steel masses varying by a factor of 5.4; although those studies were perhaps not highly detailed, the comparison indicates significant uncertainty in estimating mass data across the industry even for a single country. As another example of the potential uncertainty in any estimates of RSM masses, Lasch et al. (1984) present a generic estimate for a large light-water reactor (LWR) (in the 900- to 1,300-MWe range) of 1,100 metric tons (t) of activated steel (plus 400 t of activated reinforced concrete). If 20% by weight of this reinforced concrete is steel (reinforcing bar, or rebar), the Lasch data imply about 1,200 t of activated steel, only about 35–40% of the values used in the PWR and BWR reference plants of this report. Lasch et al. (1984) give a generic estimate of 7,800 t of activated steel for an AGR; this can be compared with the total of 2,265 t of activated carbon steel, iron, and stainless steel for the reference AGR plant based on the detailed tables of Regan et al. (1984).

Three reference reactors are used, without adjustment for electrical output rating, to develop scrap metal estimates for Magnox plants. However, the generic estimate by Lasch et al. (1984) (2,700 t of activated steel from each United Kingdom GCR, not counting activated steel rebar) is well in excess of the amount of activated iron and steel in each of these three reference plants.

Stainless steel is defined as described in Section 3.3.3; thus, nickel and nickel alloys are included in the stainless steel category. Zirconium is a significant component only in the Canadian deuterium-uranium (CANDU) and RBMK reactor types. The individual reference plants are described in the following subsection.

A.2.2 Plant-Specific Methodology

A.2.2.1 Advanced Gas-Cooled Reactor (AGR)

The comprehensive description of components and activation calculations for the Torness and Heysham AGR plants by Regan et al. (1984) was used to provide the carbon steel and iron data and the stainless steel data for the reactor block of the AGR reference plant. This reference plant was used for all United Kingdom AGRs, without adjustment for electrical output rating. The generic PWR reference plant data were used for copper, aluminum, structural steel, and lead in the rest of the plant, with the exception of the nonradioactive copper value, which was reduced to 3,900 t.

A.2.2.2 1,000-MWe Boiling-Water Reactor (BWR)

The reference 1,000-MWe BWR was used to estimate scrap from all BWR plants. The quantities of iron and steel were estimated by adjusting the PWR reference plant data for BWR characteristics: less heat-transport piping and component material, absence of steam generators, more ex-vessel containment, and more ex-vessel structure. The BWR reference plant scrap carbon steel and iron is distributed as follows: 5,000 t suspect radioactive, 6,700 t surface-contaminated — removable, and 3,500 t activated. Scrap metal in the stainless steel category is allocated as follows: negligible quantities of suspect radioactive, 600 t of surface-contaminated — removable, and 670 t of activated metal. In contrast, El-Bassioni (1980) gives a total mass of 10,000 t of carbon steel and iron for a BWR. The copper, aluminum, and lead masses assigned to the reference 1,000-MWe BWR plant were the same as those assigned to the reference 1,000-MWe PWR plant.

A.2.2.3 Pressurized Heavy-Water Reactor (PHWR)

Three different designs of heavy-water-moderated reactor are included in this category. The main group is the CANDU series. These reactors are distinguished by a low-pressure moderator in a calandria. The fuel channels are horizontal zirconium/niobium alloy pressure tubes designed to permit on-line refueling. The Indian Department of Atomic Energy now designs CANDU plants for domestic use. Variations on this design that are included in this category are reactors with light-water cooling or gas cooling, although demonstration plants of less than 100 MWe are not included. Also, there are a few PHWRs that are essentially heavy-water-filled PWRs. Because of a lack of specific information, these types of reactors were treated as if they were CANDU PHWRs.

The mass estimates were based on reactor estimates for various plants representing design evolution; some equipment masses were taken from Nuclear Engineering International (1970); plant control information was from Nuclear Engineering International (1993) and the PWR structural/systems information. The reference plant chosen was Darlington (881 MWe) as the most evolved unit, and all units were scaled by the 2/3 power rule.

The calandria and all its related appurtenances were assumed to be stainless steel. The end shields, which permit the on-line refueling operations, include some carbon steel. However, the close interfaces with the calandria and heavy water suggest that these shields include several alloys, and, therefore, they were included with the calandria in the activated stainless steel values (2,100 t). The steam generators are stainless, and the tubes are various high-nickel alloys; therefore, the component was treated as a unit. The whole mass was included with the cleanable stainless because some of the components typically fabricated from carbon steel for light-water reactors are made of stainless steel in heavy-water systems. The PHWR reference has a suspect radioactive stainless mass of 290 t, 2,000 t surface-contaminated — removable stainless, and 200 t of fixed, including an allowance for waste systems.

Two special add-ons were included in the stainless category. The Pickering reactors have 12 steam generators each, whereas each of the larger reactors has 4 generators. The scaling assumed that most reactors have four steam generators, including small reactors in the 200-MWe-range. To compensate for the scaling rule, an additional 440 t of metal was included in the surface-contaminated — removable stainless category for the Pickering reactors. The Pickering A Station Units 1-4 have a dump tank for emergency shutdown. Some of the other early units are also described as including control by "moderator level" (Nuclear Engineering International 1993). Therefore, it was inferred that these units also included dump tanks (e.g., Douglas Point [Nuclear Engineering 1964]), which were closely associated with the reactor structure. For this reason, the Pickering Units 1-4 (1,500 t), Douglas Point, MAPS Units 1-2, RAPS Units 1-2 (all 825 t), and KANUPP (600 t) all include prescaled dump tank masses in the activated stainless steel component.

The carbon steel masses were based on the corresponding 1,000-MWe PWR values, except that some mass was transferred to the suspect radioactive and surface-contaminated — removable stainless steel categories because the fluid is heavy water. Because most of the activated carbon steel was for cell and containment liners and similar components, this value was left unchanged from that of the reference PWR. Although the PWR values are for a 1,000-MWe plant, while the reference PHWR is only 881 MWe, natural uranium reactors tend to be somewhat larger than those using slightly enriched uranium. Thus, the masses were not scaled down for the PHWR reference plant. Similarly, the copper, aluminum, and lead values and scaling treatments were as for the PWRs. This approach was also appropriate since the copper and aluminum values were based on the 900-MWe French PWR series. The pressure tubes are a zirconium-niobium alloy. Only a relatively small difference in masses was quoted for the Pickering and the Darlington units, and there are almost as many units larger than Pickering as there are units smaller than Pickering. A constant zirconium mass was used, equal to the Pickering value of 25 t.

A.2.2.4 High-Temperature, Gas-Cooled Reactors (HTGRs)

The only two high-temperature, gas-cooled reactors (HTGRs) in the data sheets are Fort St. Vrain and the THTR-300. Both of these had prestressed concrete pressure vessels, and the AGR materials data were used as a reasonable approximation for these HTGRs.

A.2.2.5 Magnox with Steel Vessels (Magnox I and II)

The mass estimates for the Magnox stations were derived from several sources. In the Magnox stations' period of nuclear development, the basic design requirements were amply described, but the design details were clearly regarded as proprietary.

In the mass estimates, the base boiler (for example) was defined for the Dungeness nuclear power station by using shell information from an industry magazine issue devoted to the plant (Nuclear Power 1961), with tube masses approximated from Regan et al. (1984) and adjusted according to thermal power rating. This method partially allows for the temperature differences between the AGR and Magnox plants by considering unit thermal power rather than plant electrical ratings. All the tubes were assumed to be mild steel alloys. The total boiler mass per plant was then scaled from this base value according to plant output and number of boilers per plant. The duct length was estimated from the Nuclear Power wall chart for Dungeness (Nuclear Power 1961). The boiler masses tend to fall into two groups, the dividing line being about 200 MWe per reactor. Consequently, the boiler and duct masses were averaged into two groups, designated in the tables as Magnox I (200 MWe or less) and Magnox II (more than 200 MWe). The power used in these calculations was the design rating, not the reduced operational rating given in the detailed data sheets.

The vessel mass used is an average of the Magnox steel vessels calculated from Nuclear Engineering International (1993). The vessel size ranges are relatively close (almost independent of reactor power), so an average was used. The structural steel values were scaled from those of the LWR reference plant by the 2/3-power rule, to 150 MWe and 250 MWe for Magnox I and II, respectively. Because Magnox plants use natural uranium, a Magnox complex is larger than that of a comparable enriched-fuel reactor. Thus, the scaling factors were increased above those given by the 2/3-power rule (0.3 and 0.4, respectively), to 0.4 and 0.5, respectively. The same ratios were used for the copper. For aluminum and lead, however, the reduced values were small and it was decided to exclude these metals. The Magnox reactors contain relatively small quantities of stainless steel, primarily in instrumentation systems, and a nominal estimate was included. The turbine generator and condenser masses were estimated with data from Leclercq (1986) for the two reactor size groups. The specific reference plant values for Magnox I and II are given below.

A.2.2.6 Magnox I

The first reference reactor for the United Kingdom Magnox plants represents reactors of 200 MWe or less. Estimates were obtained from evaluation of the specific components. Carbon steel and iron values are 3,800 t of suspect radioactive, 4,950 t of surface-contaminated — removable, negligible quantities of surface-contaminated — fixed, and 1,000 t of activated. An allowance of 100 t for activated stainless steel is included. Copper is allocated as follows: 1,900 t of suspect radioactive, 50 t of surface-contaminated — removable, and 50 t of activated. Aluminum and lead quantities are negligible. Chinon A2 is included with Magnox I plants.

A.2.2.7 Magnox II

Magnox II represents Magnox reactors greater than 200 MWe, without prestressed concrete pressure vessels. Estimates were obtained from evaluation of the specific components. Carbon steel and iron values are 4,690 t of suspect radioactive, 6,225 t of surface-contaminated — removable, negligible quantities of surface-contaminated — fixed, and 1,000 t of activated. An allowance of 100 t is included for activated stainless steel. Copper is allocated as follows: 2,400 t of suspect radioactive, 50 t of surface-contaminated — removable, and 50 t of activated. Aluminum and lead are negligible.

A.2.2.8 Magnox with Prestressed Concrete Vessels (Magnox III)

A third group of Magnox plants, designated Magnox III in the tables, was defined as those with prestressed concrete pressure vessels and internal boilers. They are the direct predecessors of the AGRs, and most of them have about the same rating as the AGRs. The AGRs are in the 500- to 700-MWe range, while most of the prestressed concrete vessel Magnox plants are in the 480- to 590-MWe range, including French and British units. The only exceptions are the two Oldbury units, at 300 MWe each. The French plants had boilers below the core (e.g. St. Laurent), and the British units have the annular boilers outboard of the graphite. For a useful first approximation, all the Magnox III plants are allocated the same metals distribution as the AGRs. Plants in this category include Bugey 1, Chinon A3, Oldbury 1 and 2, St. Laurent A1 and A2, and Wylfa 1 and 2.

A.2.2.9 1,000-MWe Pressurized Water Reactor (PWR)

The 1,000-MWe PWR reference plant was used to estimate scrap from all non-former Soviet Union PWR plants. The iron and steel data for this plant were based on a generic (but highly detailed) design study of a 1,000-MWe U.S.A. plant (Bryan and Dudley 1974, based on United Engineers and Constructors Inc. 1972), checked against French 900-MWe data (Chapuis et al. undated), a study on decommissioning a 1,095-MWe U.S.A. plant (Smith et al. 1978), and the El-Bassioni (1980) compilation. Estimates are consistent with IAEA figures (IAEA 1988).

Total carbon-steel and iron masses ranged from 25,000 t (the 900-MWe plant) to 33,000 t (the 1,000-MWe plant). El-Bassioni (1980) quotes a range of 10,000 to 54,000 t for PWR plants. Of the 33,000 t total in the generic 1,000-MWe plant, about 13,300 t is rebar, which is difficult and expensive to recycle from concrete. Subtracting 15,000 t for rebar and other unavailable iron and steel yields a reference plant total of 18,000 t of scrap carbon steel and iron. This steel and iron is distributed as follows: 8,290 t of suspect radioactive, 6,700 t of surface-contaminated — removable (Chapuis et al. [undated] suggest this category should be about 20% of the total), and 2,940 t of activated.

Scrap metal in the stainless steel category is allocated on the basis of the detailed plant accounting sheets as follows: negligible quantities of suspect radioactive, 900 t of

surface-contaminated — removable, 300 t of surface-contaminated — fixed, and 670 t of activated. (Of these stainless steel masses, the steam generator accounts for 500 t of surface-contaminated — removable and all 300 t of the surface-contaminated — fixed.) Copper and aluminum reference plant data were taken from Garbay and Chapuis (1989), who reference about 5,000 t of copper and about 100 t of aluminum in the standard French 900-MWe plant. These metals are located primarily in the electrical and instrumentation and control systems. On the basis of Garbay and Chapuis' estimates of contamination and activation of cables, copper is allocated as follows: 4,900 t of suspect radioactive, 80 t of surface-contaminated — removable, and 20 t of activated. Aluminum is allocated as 80 t of suspect radioactive, 15 t of surface-contaminated — removable, and 5 t of activated scrap. The El-Bassioni "model light-water reactor" value of 20 t of lead is categorized as suspect radioactive and used for the reference PWR.

A.2.2.10 RBMK (former Soviet Union)

The reference RBMK plant is used for all former Soviet Union RBMK plants without adjustment for plant electrical output. Very little information has been published on details of former Soviet Union RBMK plants. The 1,000-MWe VVER reference plant data are used for all RBMK, with the addition of 100 t of activated zirconium alloy to complete the rough estimate of metal per RBMK plant. (Emelyanov et al. [1982] indicate that an RBMK plant will contain about 90 t or more of zirconium alloy in the form of activated pressure tubes from the in-core region.)

A.2.2.11 440-MWe VVER (former Soviet Union PWR)

The former Soviet Union deployed 440-MWe VVER plants as a class, followed, with overlap, by the 1,000-MWe VVER class. The 440-MWe VVER reference plant is used for all 440-MWe-class VVER plants, without adjustment for plant electrical output. A compilation of open literature data (DOE 1987) was the basic reference for the 440-MWe plants. Data for the mature Model 213 was used for the reference VVER 440-MWe plant. The copper, aluminum and lead data for the reference 1,000-MWe PWR were adjusted to 440-MWe nominal electrical output by applying the scaling relationship that mass is proportional to output to the two-thirds power. This calculation yields values of 2,840, 46, and 12 t for suspect radioactive, surface-contaminated — removable, and activated copper, respectively; values of 46, 9, and 2 t for suspect radioactive, surface-contaminated — removable, and activated aluminum; and 12 t of suspect radioactive lead.

A.2.2.12 1,000-MWe VVER (former Soviet Union PWR)

The 1,000-MWe VVER reference plant is used for all 1,000-MWe-class VVERs, without adjustment for plant electrical output. The U.S. Department of Energy (DOE 1987) presents additional data on specific systems of the 1,000-MWe VVER and also generic plant mass-to-capacity ratios of 43 and 30 t of equipment/MWe for the 440-MWe Model 213 and

1,000-MWe VVER, respectively. On the basis of these mass ratios, the 1,000-MWe VVER total metal mass is about 1.6 times that of the mature Model 213 VVER 440. That ratio was used to complete the VVER 1,000-MWe calculations. The actual scaling factor of 1.6 is in good agreement with that obtained by scaling total masses proportional to the generic relationship of (electrical output)$^{2/3}$, which yields a total mass ratio of 1.7 for these two plant types. Reference 1,000-MWe PWR plant data for copper, aluminum and lead were used for the 1,000-MWe VVER.

A.3 REFERENCE PLANT PARAMETERS AND ESTIMATED METAL MASSES

This section presents summary tables listing the reference plant parameters and the estimated metal masses for each. In the plant information section at the top of each table, the row labelled "Identifier" consists of an identifying sequence number, a country identifier, and an abbreviated description of the reactor type. The "vendor" row identifies the main contractors for the reactor system and, in some cases, the hardware contributor. The architect/engineer row identifies the firm involved in laying out the reactor. In the metal quantities sections of the tables, the category "non-radioactive" is equivalent to "suspect radioactivity," the category "surf. contam.-cleanable" is equivalent to "surface-contaminated — removable," and the category "surf. contam.-non-clnbl." is equivalent to surface-contaminated — fixed.

U.S. BWRs and Misc.

	Browns Ferry 1	Browns Ferry 2	Browns Ferry 3	Brunswick 1	Brunswick 2	Clinton 1	Cooper	Dresden 1	Dresden 2	Dresden 3	Duane Arnold	Edwin I. Hatch 1	Edwin I. Hatch 2	Fermi 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	161USAB	165USAB	203USAB	262USAB	238USAB	426USAB	162USAB	23USAB	129USAB	132USAB	237USAB	194USAB	211USAB	247USAB
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1974	1975	1977	1977	1975	1987	1974	1960	1970	1971	1974	1975	1979	1988
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Shut down	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1065	1065	1065	767	754	930	764	200	772	773	538	741	761	1075
Vendor	GE	GE	GE	GE	GE	GE	GE		GE	GE	GE	GE	GE	GE
A/E	Utility	Utility	Utility	UE&C	UE&C	S&L	B&R		S&L	S&L	Bechtel	Util./Bchtl	Bechtel	Utility
Pre or Post TMI	Pre	Pre	Pre	Pre	Pre	Post	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	2	2	1
Cooling				River	River	Lake	River		River	River	Tower	Ind.draft twr	Ind.draft twr	
Date EOL metal available	2024	2025	2027	2027	2025	2037	2024	2010	2020	2021	2024	2025	2029	2038
Quantity of metal (tonnes):														
Aluminum Non-radioactive	83	83	83	67	66	76	67	27	67	67	53	66	67	84
Surf. contam.-cleanable	16	16	16	13	12	14	13	5	13	13	10	12	13	16
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	4	4	5	4	2	4	4	3	4	4	5
Copper Non-radioactive	5110	5110	5110	4106	4059	4669	4095	1676	4124	4127	3241	4012	4084	5142
Surf. contam.-cleanable	83	83	83	67	66	76	67	27	67	67	53	66	67	84
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	21	21	21	17	17	19	17	7	17	17	13	16	17	21
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5214	5214	5214	4190	4142	4764	4179	1710	4208	4211	3307	4094	4168	5247
Surf. contam.-cleanable	6987	6987	6987	5614	5550	6384	5599	2291	5638	5643	4432	5486	5585	7031
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3650	3650	3650	2933	2899	3335	2925	1197	2945	2948	2315	2866	2917	3673
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	626	626	626	503	497	572	501	205	505	505	397	491	500	630
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	699	699	699	561	555	638	560	229	564	564	443	549	558	703
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0	0

U.S. BWRs and Misc.

	Grand Gulf	Hope Creek	James A. Fitzpat.	LaSalle County 1	LaSalle County 2	Limerick 1	Limerick 2	Millstone 1	Monti-cello	Nine Mile Point 1	Nine Mile Point 2	Oyster Creek	Peach Bottom 2	Peach Bottom 3
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	359USAB	269USAB	168USAB	293USAB	301USAB	272USAB	216USAB	131USAB	151USAB	108USAB	333USAB	96USAB	160USAB	193USAB
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1985	1986	1975	1984	1984	1986	1990	1971	1971	1969	1988	1969	1974	1974
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1142	1031	757	1036	1036	1055	1055	660	536	610	1080	610	1100	1100
Vendor	GE	GE	GE	GE	GE	GE	GE	GE	GE	GE	GE	GE	GE	GE
A/E	Bechtel	Bechtel	S&W	S&L	S&L	Bechtel	Bechtel	Ebasco	Bechtel	Utility	S&W	B&R/GE	Bechtel	Bechtel
Pre or Post TMI	Post	Post	Pre	Post	Post	Post	Post	Pre	Pre	Pre	Post	Pre	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Tower	Tower	Lake	Lake	Lake			Sea	River	Lake	Tower	Cnl to bay		
Date EOL metal available	2035	2036	2025	2034	2034	2036	2040	2021	2021	2019	2038	2019	2024	2024
Quantity of metal (tonnes):														
Aluminum Non-radioactive	87	82	66	82	82	83	83	61	53	58	84	58	85	85
Surf. contam.-cleanable	16	15	12	15	15	16	16	11	10	11	16	11	16	16
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	4	5	5	5	5	4	3	4	5	4	5	5
Copper Non-radioactive	5354	5001	4070	5017	5017	5078	5078	3714	3233	3524	5158	3524	5221	5221
Surf. contam.-cleanable	87	82	66	82	82	83	83	61	53	58	84	58	85	85
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	22	20	17	20	20	21	21	15	13	14	21	14	21	21
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5463	5103	4153	5119	5119	5182	5182	3790	3299	3596	5263	3596	5328	5328
Surf. contam.-cleanable	7320	6838	5565	6860	6860	6943	6943	5079	4421	4819	7053	4819	7140	7140
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3824	3572	2907	3584	3584	3627	3627	2653	2309	2517	3684	2517	3730	3730
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	656	612	498	614	614	622	622	455	396	432	632	432	639	639
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	732	684	557	686	686	694	694	508	442	482	705	482	714	714
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0	0

U.S. BWRs and Misc.	Perry 1	Perry 2	Pilgrim	Quad Cities 1	Quad Cities 2	River Bend	Susque-hanna 1	Susque-hanna 2	Vermont Yankee	WNP-2	Fort St. Vrain	Hanford N
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	360USAB	516USAB	188USAB	154USAB	155USAB	374USAB	295USAB	304USAB	156USAB	324USAB	137USAG	58USAG
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	HTGR	LWGR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1987		1972	1973	1973	1986	1983	1985	1972	1984	1979	1966
Status	Operating	Under Cons	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Shut down	Shut down
Size (MWe) (Net)	1205	1205	670	769	769	936	1032	1038	504	1100	330	845
Vendor	GE	GE	GE	GE	GE	GE	GE	GE	GE	GE	GGA	Kaiser
A/E	Gilbert	Gilbert	Bechtel	S&L	S&L	S&W	Bechtel	Bechtel	Ebasco	B&R	Sarg.&Lun	B&R/GE
Pre or Post TMI	Post	Post	Pre	Pre	Pre	Post	Post	Post	Pre	Post	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Nat.draft twr	Nat.draft twr		River	River	Tower	Nat.draft twr	Nat.draft twr		Frcd drft twr	Tower	River
Date EOL metal available	2037	2053	2022	2023	2023	2036	2033	2035	2022	2034	2029	2016
Quantity of metal (tonnes):												
Aluminum Non-radioactive	91	91	61	67	67	77	82	82	51	85	80	80
Surf. contam.-cleanable	17	17	11	13	13	14	15	15	9	16	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	6	6	4	4	4	5	5	5	3	5	5	5
Copper Non-radioactive	5549	5549	3752	4113	4113	4689	5004	5023	3103	5221	3900	4900
Surf. contam.-cleanable	91	91	61	67	67	77	82	82	51	85	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	23	23	15	17	17	19	20	21	13	21	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5662	5662	3828	4197	4197	4784	5106	5126	3167	5328	12770	19248
Surf. contam.-cleanable	7587	7587	5130	5624	5624	6411	6842	6869	4243	7140	5630	7156
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	69
Activated	3963	3963	2680	2938	2938	3349	3574	3588	2217	3730	2100	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	60	0
Surf. contam.-cleanable	679	679	459	504	504	574	613	615	380	639	900	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	759	759	513	562	562	641	684	687	424	714	165	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	100

U.S. PWRs

	Alvin W. Vogtle 1	Alvin W. Vogtle 2	Arkansas Nuclear 1	Arkansas Nuclear 2	Beaver Valley 1	Beaver Valley 2	Bellefonte 1	Bellefonte 2	Braidwood 1	Braidwood 2	Byron 1	Byron 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	334USAP	520USAP	197USAP	288USAP	205USAP	327USAP	294USAP	298USAP	424USAP	440USAP	326USAP	435USAP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1987	1989	1974	1980	1976	1987			1988	1988	1985	1987
Status	Operating	Operating	Operating	Operating	Operating	Operating	Under Const	Under Const	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1100	1097	836	858	810	833	1213	1213	1120	1120	1105	1105
Vendor	Westinghouse	Westinghouse	B & W	C-E	Westinghouse	Westinghouse	B & W	B & W	Westinghouse	Westinghouse	Westinghouse	Westinghouse
A/E	Util./Bechtel	Util./Bechtel	Bechtel	Bechtel	S&W	S&W	Utility	Utility	S&L	S&L	S&L	S&L
Pre or Post TMI	Post	Post	Pre	Post	Pre	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Tower		Lake	Tower	River				Lake	Lake	Tower	Tower
Date EOL metal available	2037	2039	2024	2030	2026	2037	2053	2053	2038	2038	2035	2037
Quantity of metal (tonnes):												
Aluminum Non-radioactive	85	85	71	72	70	71	91	91	86	86	86	86
Surf. contam.-cleanable	16	16	13	14	13	13	17	17	16	16	16	16
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	4	5	4	4	6	6	5	5	5	5
Copper Non-radioactive	5221	5212	4348	4424	4258	4338	5573	5573	5285	5285	5237	5237
Surf. contam.-cleanable	85	85	71	72	70	71	91	91	86	86	86	86
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	21	21	18	18	17	18	23	23	22	22	21	21
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	8834	8818	7357	7485	7204	7339	9429	9429	8941	8941	8861	8861
Surf. contam.-cleanable	7140	7127	5946	6050	5822	5932	7620	7620	7226	7226	7161	7161
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3133	3127	2609	2655	2555	2603	3344	3344	3171	3171	3142	3142
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	959	957	799	813	782	797	1024	1024	971	971	962	962
Surf. contam.-non-clnbl	320	319	266	271	261	266	341	341	324	324	321	321
Activated	714	713	595	605	582	593	762	762	723	723	716	716
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.S. PWRs

	Callaway	Calvert Cliffs 1	Calvert Cliffs 2	Catawba 1	Catawba 2	Comanche Peak 1	Comanche Peak 2	Crystal River 3	Davis-Besse	Diablo Canyon 1	Diablo Canyon 2	Donald C. Cook 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	427USAP	199USAP	206USAP	299USAP	302USAP	358USAP	367USAP	201USAP	241USAP	202USAP	243USAP	200USAP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1985	1975	1977	1985	1986	1990		1977	1978	1985	1986	1975
Status	Operating	Operating	Operating	Operating	Operating	Operating	Under Const	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1125	825	825	1129	1129	1150	1150	821	877	1073	1087	1020
Vendor	Westinghouse	C-E	C-E	Westinghouse	Westinghouse	Westinghouse	Westinghouse	B & W	B & W	Westinghouse	Westinghouse	Westinghouse
A/E	Bechtel	Bechtel	Bechtel	Utility	Utility	Gibbs & Hill	Gibbs & Hill	Gilbert	Bechtel	Utility	Utility	Utility
Pre or Post TMI	Post	Pre	Pre	Post	Post	Post	Post	Pre	Pre	Post	Post	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Tower	Bay				Lake	Lake	Sea	Nat.draft tower	Sea	Sea	River
Date EOL metal available	2035	2025	2027	2035	2036	2040	2053	2027	2028	2035	2036	2025
Quantity of metal (tonnes):												
Aluminum Non-radioactive	87	70	70	87	87	88	88	70	73	84	85	81
Surf. contam.-cleanable	16	13	13	16	16	16	16	13	14	16	16	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	4	4	5	5	5	5	4	5	5	5	5
Copper Non-radioactive	5300	4310	4310	5313	5313	5379	5379	4296	4489	5136	5180	4965
Surf. contam.-cleanable	87	70	70	87	87	88	88	70	73	84	85	81
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	22	18	18	22	22	22	22	18	18	21	21	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	8967	7292	7292	8988	8988	9100	9100	7269	7595	8689	8764	8400
Surf. contam.-cleanable	7247	5894	5894	7264	7264	7354	7354	5874	6139	7022	7083	6789
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3180	2586	2586	3188	3188	3227	3227	2578	2694	3081	3108	2979
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	974	792	792	976	976	988	988	789	825	943	951	912
Surf. contam.-non-clnbl	325	264	264	325	325	329	329	263	275	314	317	304
Activated	725	589	589	726	726	735	735	587	614	702	708	679
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.S. PWRs

	Donald C. Cook 2	Fort Calhoun	Haddam Neck	Indian Point 1	Indian Point 2	Indian Point 3	Joseph M. Farley 1	Joseph M. Farley 2	Kewaunee	Maine Yankee	McGuire 1	McGuire 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	208USAP	166USAP	94USAP	24USAP	135USAP	234USAP	261USAP	291USAP	192USAP			
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1978	1973	1968	1963	1974	1976	1977	1981	1974	1972	1981	1984
Status	Operating	Operating	Operating	Shut down	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1060	478	590	257	970	965	814	824	503	840	1129	1129
Vendor	Westinghouse	C-E	Westinghouse		Westinghouse	Westinghouse	Westinghouse	Westinghouse	Westinghouse	C-E	Westinghouse	Westinghouse
A/E	Utility	Gibbs & Hill	S&W		UE & C	UE & C	Util./Bchtl	Util./Bchtl	Fluor	S&W	Utility	Utility
Pre or Post TMI	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Post	Pre	Pre	Post	Post
No. of steam turbines	1	1		1	1	1	1	1	1			
Cooling	Lake		River		River		Forced drft twr	Forced drft twr			Lake	
Date EOL metal available	2028	2023	2018	2013	2024	2026	2027	2031	2024	2022	2031	2034
Quantity of metal (tonnes):												
Aluminum Non-radioactive	83	49	56	32	78	78	70	70	51	71	87	87
Surf. contam.-cleanable	16	9	11	6	15	15	13	13	9	13	16	16
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	3	4	2	5	5	4	4	3	4	5	5
Copper Non-radioactive	5094	2996	3447	1981	4802	4785	4272	4307	3099	4362	5313	5313
Surf. contam.-cleanable	83	49	56	32	78	78	70	70	51	71	87	87
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	21	12	14	8	20	20	17	18	13	18	22	22
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	8618	5068	5832	3351	8123	8095	7227	7286	5243	7380	8988	8988
Surf. contam.-cleanable	6965	4096	4713	2708	6565	6543	5841	5889	4238	5965	7264	7264
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3056	1797	2068	1188	2881	2871	2563	2584	1859	2617	3188	3188
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	936	550	633	364	882	879	785	791	569	801	976	976
Surf. contam.-non-clnbl	312	183	211	121	294	293	262	264	190	267	325	325
Activated	697	410	471	271	657	654	584	589	424	596	726	726
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.S. PWRs

	Millstone 2	Millstone 3	North Anna 1	North Anna 2	Oconee 1	Oconee 2	Oconee 3	Palisades	Palo Verde 1	Palo Verde 2	Palo Verde 3	Point Beach 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	239USAP	528USAP	207USAP	209USAP	158USAP	163USAP	196USAP	153USAP	431USAP	448USAP	461USAP	130USAP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1975	1986	1978	1980	1973	1974	1974	1971	1986	1986	1988	1970
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	862	1146	911	909	846	846	846	768	1221	1221	1221	485
Vendor	C - E	Westinghouse	Westinghouse	Westinghouse	B & W	B & W	B & W	C - E	C-E	C-E	C-E	Westinghouse
A/E	Bechtel	S&W	S&W	S&W	Util./Bchtl	Util./Bchtl	Util./Bchtl	Bechtel	Bechtel	Bechtel	Bechtel	Bechtel
Pre or Post TMI	Pre	Post	Pre	Post	Pre	Pre	Pre	Pre	Post	Post	Post	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Sea	Sea	Bay	River				Tower	Tower	Tower	Tower	Lake
Date EOL metal available	2025	2036	2028	2030	2023	2024	2024	2021	2036	2036	2038	2020
Quantity of metal (tonnes):												
Aluminum Non-radioactive	72	88	75	75	72	72	72	67	91	91	91	49
Surf. contam.-cleanable	14	16	14	14	13	13	13	13	17	17	17	9
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	4	4	4	4	6	6	6	3
Copper Non-radioactive	4438	5366	4605	4598	4383	4383	4383	4109	5598	5598	5598	3025
Surf. contam.-cleanable	72	88	75	75	72	72	72	67	91	91	91	49
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	18	22	19	19	18	18	18	17	23	23	23	12
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	7509	9078	7791	7779	7415	7415	7415	6952	9470	9470	9470	5117
Surf. contam.-cleanable	6068	7337	6296	6287	5993	5993	5993	5619	7654	7654	7654	4136
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2663	3220	2763	2759	2630	2630	2630	2466	3359	3359	3359	1815
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	815	986	846	845	805	805	805	755	1028	1028	1028	556
Surf. contam.-non-clnbl	272	329	282	282	268	268	268	252	343	343	343	185
Activated	607	734	630	629	599	599	599	562	765	765	765	414
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.S. PWRs

	Point Beach 2	Prairie Island 1	Prairie Island 2	Rancho Seco	Robinson 2	R. E. Ginna	Saint Lucie 1	Saint Lucie 2	Salem 1	Salem 2	San Onofre 1	San Onofre 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	157USAP	191USAP	198USAP	167USAP	150USAP	128USAP	242USAP	375USAP	169USAP	170USAP	95USAP	296USAP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1972	1973	1974	1975	1971	1970	1976	1983	1977	1981	1968	1983
Status	Operating	Operating	Operating	Shut down	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	485	503	500	913	683	470	839	839	1106	1106	436	1070
Vendor	Westinghouse	Westinghouse	Westinghouse		Westinghouse	Westinghouse	C-E	C-E	Westinghouse	Westinghouse	Westinghouse	C-E
A/E	Bechtel	Fluor	Fluor		Ebasco	Gilbert	Ebasco	Ebasco	Utility	Utility	Bechtel	Bechtel
Pre or Post TMI	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Post	Pre	Post	Pre	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1		1
Cooling	Lake			Nat.draft tower		Lake	Sea	Sea	River	River	Sea	Sea
Date EOL metal available	2022	2023	2024	2025	2021	2020	2026	2033	2027	2031	2018	2033
Quantity of metal (tonnes):												
Aluminum Non-radioactive	49	51	50	75	62	48	71	71	86	86	46	84
Surf. contam.-cleanable	9	9	9	14	12	9	13	13	16	16	9	16
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	3	3	5	4	3	4	4	5	5	3	5
Copper Non-radioactive	3025	3099	3087	4612	3800	2962	4359	4359	5240	5240	2817	5126
Surf. contam.-cleanable	49	51	50	75	62	48	71	71	86	86	46	84
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	13	13	19	16	12	18	18	21	21	11	21
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5117	5243	5222	7802	6429	5011	7374	7374	8866	8866	4767	8672
Surf. contam.-cleanable	4136	4238	4221	6306	5196	4050	5960	5960	7165	7165	3852	7009
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	1815	1859	1852	2767	2280	1777	2615	2615	3144	3144	1690	3076
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	556	569	567	847	698	544	801	801	963	963	517	942
Surf. contam.-non-clnbl	185	190	189	282	233	181	267	267	321	321	172	314
Activated	414	424	422	631	520	405	596	596	717	717	385	701
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.S. PWRs

	San Onofre 3	Seabrook	Sequoyah 1	Sequoyah 2	Shearon Harris	Surry 1	Surry 2	S. Texas Project 1	S. Texas Project 2	Three Mile Island 1	Three Mile Island 2	Trojan
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	306USAP	371USAP	244USAP	245USAP	335USAP	152USAP	159USAP	422USAP	434USAP	164USAP	263USAP	240USAP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1984	1990	1981	1982	1987	1972	1973	1988	1989	1974	1978	1976
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Shut down	Operating
Size (MWe) (Net)	1080	1150	1148	1148	860	781	781	1250	1250	786	792	1095
Vendor	C-E	Westinghouse	Westinghouse	Westinghouse	Westinghouse	Westinghouse	Westinghouse	Westinghouse	Westinghouse	B & W		Westinghouse
A/E	Bechtel	UE & C	Utility	Utility	Ebasco	S&W	S&W	Bechtel	Bechtel	Gilbert		Bechtel
Pre or Post TMI	Post	Post	Post	Post	Post	Pre	Pre	Post	Post	Pre	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Sea				Tower	River	River			Nat.draft tower		Tower
Date EOL metal available	2034	2040	2031	2032	2037	2022	2023	2038	2039	2024	2028	2026
Quantity of metal (tonnes):												
Aluminum Non-radioactive	84	88	88	88	72	68	68	93	93	68	68	85
Surf. contam.-cleanable	16	16	16	16	14	13	13	17	17	13	13	16
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	4	4	6	6	4	4	5
Copper Non-radioactive	5158	5379	5372	5372	4431	4156	4156	5686	5686	4173	4194	5206
Surf. contam.-cleanable	84	88	88	88	72	68	68	93	93	68	68	85
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	21	22	22	22	18	17	17	23	23	17	17	21
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	8726	9100	9089	9089	7497	7031	7031	9620	9620	7061	7096	8807
Surf. contam.-cleanable	7053	7354	7346	7346	6059	5682	5682	7775	7775	5706	5735	7118
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3095	3227	3223	3223	2659	2493	2493	3412	3412	2504	2517	3123
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	947	988	987	987	814	763	763	1044	1044	767	770	956
Surf. contam.-non-clnbl	316	329	329	329	271	254	254	348	348	256	257	319
Activated	705	735	735	735	606	568	568	777	777	571	574	712
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.S. PWRs

	Turkey Point 3	Turkey Point 4	Virgil C. Summer	Waterford 3	Watts Bar 1	Watts Bar 2	WNP-1	WNP-3	Wolf Creek	Yankee Rowe	Zion 1	Zion 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	134USAP	136USAP	325USAP	297USAP	292USAP	300USAP	425USAP	439USAP	437USAP	33USAP	190USAP	195USAP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA	USA
Start of operations	1972	1973	1984	1985					1985	1961	1973	1974
Status	Operating	Operating	Operating	Operating	Under Const	Under Const	Under Const	Under Const	Operating	Shut down	Operating	Operating
Size (MWe) (Net)	666	666	885	1075	1177	1177	1259	1240	1135	167	1040	1040
Vendor	Westinghouse	Westinghouse	Westinghouse	C-E	Westinghouse	Westinghouse	B & W	C-E	Westinghouse		Westinghouse	Westinghouse
A/E	Bechtel	Bechtel	Gilbert	Ebasco	Utility	Utility	UE & C	Ebasco	Bechtel/S&L		S&L	S&L
Pre or Post TMI	Pre	Pre	Post	Post	Post	Post	Post	Post	Post	Pre	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Channels	Channels	Lake				Forced drft twr				Lake	Lake
Date EOL metal available	2022	2023	2034	2035	2053	2053	2053	2053	2035	2011	2023	2024
Quantity of metal (tonnes):												
Aluminum Non-radioactive	61	61	74	84	89	89	93	92	87	24	82	82
Surf. contam.-cleanable	11	11	14	16	17	17	17	17	16	5	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	4	4	5	5	6	6	6	6	5	2	5	5
Copper Non-radioactive	3737	3737	4517	5142	5462	5462	5713	5658	5332	1486	5030	5030
Surf. contam.-cleanable	61	61	74	84	89	89	93	92	87	24	82	82
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	15	15	18	21	22	22	23	23	22	6	21	21
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	6322	6322	7642	8699	9241	9241	9666	9568	9020	2514	8510	8510
Surf. contam.-cleanable	5110	5110	6176	7031	7469	7469	7812	7733	7290	2032	6877	6877
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2242	2242	2710	3085	3277	3277	3428	3393	3199	892	3018	3018
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	686	686	830	944	1003	1003	1049	1039	979	273	924	924
Surf. contam.-non-clnbl	229	229	277	315	334	334	350	346	326	91	308	308
Activated	511	511	618	703	747	747	781	773	729	203	688	688
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Canada & Mexico

	Bruce 1	Bruce 2	Bruce 3	Bruce 4	Bruce 5	Bruce 6	Bruce 7	Bruce 8	Darlington 1	Darlington 2	Darlington 3	Darlington 4
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	224CDNH	225CDNH	226CDNH	227CDNH	402CDNH	403CDNH	404CDNH	405CDNH	406CDNH	407CDNH	409CDNH	411CDNH
Plant type	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR
Location	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada
Start of operations	1977	1977	1978	1979	1985	1984	1986	1987	1990	1990		
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Under Const	Under Const
Size (MWe) (Net)	769	769	769	769	860	837	860	837	881	881	881	881
Vendor	AECUDB-S	AECUDB-S	AECUDB-S	AECUDB-S	AECUMIL Vic	AECUMIL Vic	AECUMIL Vic	AECUMIL Vic	AECUDB-S	AECUDB-S	AECUMIL Vic	AECUMIL Vic
A/E	Util/AECL	Util/AECL	Util/AECL	Util/AECL	Ont. Hyd.	Ont. Hyd.	Ont. Hyd.	Ont. Hyd.	Ont. Hyd.	Ont. Hyd.	Ont. Hyd.	Ont. Hyd.
Pre or Post TMI	Pre	Pre	Pre	Pre	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake	Lake
Date EOL metal available	2027	2027	2028	2029	2035	2034	2036	2037	2040	2040	2053	2053
Quantity of metal (tonnes):												
Aluminum Non-radioactive	73	73	73	73	79	77	79	77	80	80	80	80
Surf. contam.-cleanable	14	14	14	14	15	14	15	14	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	5	5	5	5	5	5	5
Copper Non-radioactive	4475	4475	4475	4475	4822	4735	4822	4735	4900	4900	4900	4900
Surf. contam.-cleanable	73	73	73	73	79	77	79	77	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	18	18	18	18	20	19	20	19	20	20	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	7307	7307	7307	7307	7872	7731	7872	7731	8000	8000	8000	8000
Surf. contam.-cleanable	5480	5480	5480	5480	5904	5799	5904	5799	6000	6000	6000	6000
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2685	2685	2685	2685	2893	2841	2893	2841	2940	2940	2940	2940
St. Steel Non-radioactive	265	265	265	265	285	280	285	280	290	290	290	290
Surf. contam.-cleanable	1827	1827	1827	1827	1968	1933	1968	1933	2000	2000	2000	2000
Surf. contam.-non-clnbl	183	183	183	183	197	193	197	193	200	200	200	200
Activated	1918	1918	1918	1918	2066	2029	2066	2029	2100	2100	2100	2100
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	25	25	25	25	25	25	25	25	25	25	25	25

Canada & Mexico

	Douglas Point	Gentilly 1	Gentilly 2	Pickering 1	Pickering 2	Pickering 3	Pickering 4	Pickering 5	Pickering 6	Pickering 7	Pickering 8	Point Le-preau 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	78CDNH	119CDNH	354CDNH	104CDNH	105CDNH	120CDNH	122CDNH	228CDNH	229CDNH	399CDNH	401CDNH	514CDNH
Plant type	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR
Location	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada	Canada
Start of operations	1968	1972	1983	1971	1971	1972	1973	1983	1984	1985	1986	1983
Status	Shut down	Shut down	Operating	Operating	Shut down	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	206	250	638	515	515	515	515	516	516	516	516	635
Vendor	AECL	AECL	AECL	AECUDB-S	AECUDB-S	AECUDB-S	AECUDB-S	AECUDB-S	AECUDB-S	AECUDB-S	AECUDB-S	AECL
A/E	Util/AECL	AECL/Util.	Hyd-Quebec	Util/AECL	Util/AECL	Util/AECL	Util/AECL	Util/AECL	Util/AECL	Util/AECL	Util/AECL	Canatorn
Pre or Post TMI	Pre	Pre	Post	Pre	Pre	Pre	Pre	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling			River	Lake	Lake	Lake		Lake	Lake	Lake	Lake	Slt wtr cond.
Date EOL metal available	2018	2022	2033	2021	2021	2022	2023	2033	2034	2035	2036	2033
Quantity of metal (tonnes):												
Aluminum Non-radioactive	30	35	65	56	56	56	56	56	56	56	56	64
Surf. contam.-cleanable	6	6	12	10	10	10	10	10	10	10	10	12
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2	2	4	3	3	3	3	4	4	4	4	4
Copper Non-radioactive	1860	2116	3951	3426	3426	3426	3426	3430	3430	3430	3430	3939
Surf. contam.-cleanable	30	35	65	56	56	56	56	56	56	56	56	64
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	8	9	16	14	14	14	14	14	14	14	14	16
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	3036	3455	6451	5593	5593	5593	5593	5600	5600	5600	5600	6431
Surf. contam.-cleanable	2277	2591	4839	4195	4195	4195	4195	4200	4200	4200	4200	4823
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	1116	1270	2371	2055	2055	2055	2055	2058	2058	2058	2058	2363
St. Steel Non-radioactive	110	125	234	203	203	203	203	203	203	203	203	233
Surf. contam.-cleanable	759	864	1613	1398	1398	1398	1398	1400	1400	1400	1400	1608
Surf. contam.-non-clnbl	76	86	161	140	140	140	140	140	140	140	140	161
Activated	797	907	1693	1468	1468	1468	1468	1470	1470	1470	1470	1688
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	25	25	25	25	25	25	25	25	25	25	25	25

Canada & Mexico	Point Le-preau 2	Laguna Verde 1	Laguna Verde 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor
Identifier	860CDNH	259MXB	264MXB
Plant type	PHWR	BWR	BWR
Location	Canada	Mexico	Mexico
Start of operations		1989	
Status	Planned	Operating	Under const.
Size (MWe) (Net)	400	654	654
Vendor		GE	GE
A/E		Ebasco/CFE	Ebasco/CFE
Pre or Post TMI	Post	Post	Post
No. of steam turbines	1	1	1
Cooling			
Date EOL metal available	Unknown	2039	2053
Quantity of metal (tonnes):			
Aluminum Non-radioactive	47	60	60
Surf. contam.-cleanable	9	11	11
Surf. contam.-non-clnbl	0	0	0
Activated	3	4	4
Copper Non-radioactive	2895	3692	3692
Surf. contam.-cleanable	47	60	60
Surf. contam.-non-clnbl	0	0	0
Activated	12	15	15
Lead Non-radioactive	20	20	20
Surf. contam.-cleanable	0	0	0
Surf. contam.-non-clnbl	0	0	0
Activated	0	0	0
Steel & Iron Non-radioactive	4726	3767	3767
Surf. contam.-cleanable	3544	5048	5048
Surf. contam.-non-clnbl	0	0	0
Activated	1737	2637	2637
St. Steel Non-radioactive	171	0	0
Surf. contam.-cleanable	1181	452	452
Surf. contam.-non-clnbl	118	0	0
Activated	1240	505	505
Zirconium Non-radioactive	0	0	0
Surf. contam.-cleanable	0	0	0
Surf. contam.-non-clnbl	0	0	0
Activated	25	0	0

Czech & Slovakia

	Bohunice V2-2	Dukovany 1	Dukovany 2	Dukovany 3	Dukovany 4	Kecerovce 1	Kecerovce 2	Mochovce 1	Mochovce 2	Mochovce 3	Mochovce 4	North Mo-ravia 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	287CZP	319CZP	320CZP	574CZP	497CZP	806CZP	807CZP	673CZP	674CZP	675CZP	826CZP	840CZP
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	Slovakia	Czech Rep.	Czech Rep.	Czech Rep.	Czech Rep.	Czechoslovakia	Czechoslovakia	Slovakia	Slovakia	Slovakia	Slovakia	Czechoslovakia
Start of operations	1984	1985	1985	1985	1985							
Status	Operating	Operating	Operating	Operating	Operating	Planned	Planned	Under Const	Under Const	Under Const	Under Const	Planned
Size (MWe) (Net)	408	390	390	390	390	918	918	408	408	408	408	908
Vendor	Skoda	Skoda	Skoda	Skoda	Skoda			Skoda	Skoda	Skoda	Skoda	
A/E	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	2	2	2	2	2	1	1	2	2	2	2	1
Cooling						Tower						
Date EOL metal available	2034	2035	2035	2035	2035	Unknown	Unknown	2053	2053	2053	2053	Unknown
Quantity of metal (tonnes):												
Aluminum Non-radioactive	46	46	46	46	46	80	80	46	46	46	46	80
Surf. contam.-cleanable	9	9	9	9	9	15	15	9	9	9	9	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	3	3	3	3	5	5	3	3	3	3	5
Copper Non-radioactive	2840	2840	2840	2840	2840	4900	4900	2840	2840	2840	2840	4900
Surf. contam.-cleanable	46	46	46	46	46	80	80	46	46	46	46	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	12	12	12	12	20	20	12	12	12	12	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12030	12030	12030	12030	12030	19248	19248	12030	12030	12030	12030	19248
Surf. contam.-cleanable	4669	4669	4669	4669	4669	7156	7156	4669	4669	4669	4669	7156
Surf. contam.-non-clnbl	46	46	46	46	46	69	69	46	46	46	46	69
Activated	363	363	363	363	363	581	581	363	363	363	363	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1599	1599	1599	1599	1599	2600	2600	1599	1599	1599	1599	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	254	254	254	254	254	406	406	254	254	254	254	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Czech & Slovakia	North Mo-ravia 2	South Bo-hemia 1	South Bo-hemia 2	Temelin 1	Temelin 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	841CZP	873CZP	874CZP	669CZP	670CZP
Plant type	WER	WER	WER	WER	WER
Location	Czechoslovakia	Czechoslovakia	Czechoslovakia	Czech Rep.	Czech Rep.
Start of operations					
Status	Planned	Planned	Planned	Under Const	Under Const
Size (MWe) (Net)	918	918	918	918	918
Vendor				Skoda/AEE	Skoda/AEE
A/E	E-S-L	E-S-L	E-S-L	E-S-L	E-S-L
Pre or Post TMI	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1
Cooling					
Date EOL metal available	Unknown	Unknown	Unknown	2053	2053
Quantity of metal (tonnes):					
Aluminum Non-radioactive	80	80	80	80	80
Surf. contam.-cleanable	15	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0
Activated	5	5	5	5	5
Copper Non-radioactive	4900	4900	4900	4900	4900
Surf. contam.-cleanable	80	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0
Activated	20	20	20	20	20
Lead Non-radioactive	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0
Activated	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	19248
Surf. contam.-cleanable	7156	7156	7156	7156	7156
Surf. contam.-non-clnbl	69	69	69	69	69
Activated	581	581	581	581	581
St. Steel Non-radioactive	0	0	0	0	0
Surf. contam.-cleanable	2600	2600	2600	2600	2600
Surf. contam.-non-clnbl	0	0	0	0	0
Activated	406	406	406	406	406
Zirconium Non-radioactive	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0
Activated	0	0	0	0	0

France

	Belleville 1	Belleville 2	Bugey 2	Bugey 3	Bugey 4	Bugey 5	Cattenom 1	Cattenom 2	Chinon B1	Chinon B2	Chinon B3	Chinon B4
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	609FP	610FP	323FP	356FP	415FP	507FP	630FP	613FP	578FP	579FP	633FP	634FP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	France	France	France	France	France	France	France	France	France	France	France	France
Start of operations	1988	1988	1979	1979	1979	1980	1987	1988	1984	1984	1987	1988
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1310	1310	920	920	900	900	1300	1300	870	870	920	920
Vendor	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome
A/E	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF
Pre or Post TMI	Post	Post	Pre	Pre	Pre	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling									Tower	Tower	Tower	Tower
Date EOL metal available	2038	2038	2029	2029	2029	2030	2037	2038	2034	2034	2037	2038
Quantity of metal (tonnes):												
Aluminum Non-radioactive	96	96	76	76	75	75	95	95	73	73	76	76
Surf. contam.-cleanable	18	18	14	14	14	14	18	18	14	14	14	14
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	6	6	5	5	5	5	6	6	5	5	5	5
Copper Non-radioactive	5866	5866	4635	4635	4568	4568	5837	5837	4466	4466	4635	4635
Surf. contam.-cleanable	96	96	76	76	75	75	95	95	73	73	76	76
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	24	24	19	19	19	19	24	24	18	18	19	19
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	9925	9925	7842	7842	7728	7728	9875	9875	7555	7555	7842	7842
Surf. contam.-cleanable	8022	8022	6338	6338	6246	6246	7981	7981	6106	6106	6338	6338
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3520	3520	2781	2781	2741	2741	3502	3502	2679	2679	2781	2781
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1078	1078	851	851	839	839	1072	1072	820	820	851	851
Surf. contam.-non-clnbl	359	359	284	284	280	280	357	357	273	273	284	284
Activated	802	802	634	634	625	625	798	798	611	611	634	634
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

France

	Chooz SENA	Cruas Meysse 1	Cruas Meysse 2	Cruas Meysse 3	Cruas Meysse 4	Dampierre 1	Dampierre 2	Dampierre 3	Dampierre 4	Fessen-heim 1	Fessen-heim 2	Flaman-ville 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	85FP	590FP	591FP	629FP	592FP	418FP	509FP	512FP	513FP	289FP	290FP	555FP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	France	France	France	France	France	France	France	France	France	France	France	France
Start of operations	1967	1984	1985	1984	1985	1980	1981	1981	1981	1977	1978	1986
Status	Shut down	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	305	880	915	915	880	890	890	890	890	880	880	1350
Vendor	Aceco/Fram	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome
A/E	G&H/Spie	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF
Pre or Post TMI	Pre	Post	Post	Post	Post	Post	Post	Post	Post	Pre	Pre	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling												
Date EOL metal available	2017	2034	2035	2034	2035	2030	2031	2031	2031	2027	2028	2036
Quantity of metal (tonnes):												
Aluminum Non-radioactive	36	73	75	75	73	74	74	74	74	73	73	98
Surf. contam.-cleanable	7	14	14	14	14	14	14	14	14	14	14	18
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2	5	5	5	5	5	5	5	5	5	5	6
Copper Non-radioactive	2220	4500	4618	4618	4500	4534	4534	4534	4534	4500	4500	5985
Surf. contam.-cleanable	36	73	75	75	73	74	74	74	74	73	73	98
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	9	18	19	19	18	19	19	19	19	18	18	24
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	3756	7613	7813	7813	7613	7670	7670	7670	7670	7613	7613	10126
Surf. contam.-cleanable	3036	6153	6315	6315	6153	6199	6199	6199	6199	6153	6153	8184
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	1332	2700	2771	2771	2700	2720	2720	2720	2720	2700	2700	3591
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	408	826	848	848	826	833	833	833	833	826	826	1099
Surf. contam.-non-clnbl	136	275	283	283	275	278	278	278	278	275	275	366
Activated	304	615	631	631	615	620	620	620	620	615	615	818
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

France

	Flaman-ville 2	Gravelines 1	Gravelines 2	Gravelines 3	Gravelines 4	Gravelines 5	Gravelines 6	LeBlayais 1	LeBlayais 2	LeBlayais 3	LeBlayais 4	Nogent 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	556FP	416FP	417FP	419FP	423FP	631FP	632FP	551FP	553FP	586FP	587FP	614FP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	France	France	France	France	France	France	France	France	France	France	France	France
Start of operations	1987	1980	1980	1981	1981	1985	1985	1981	1983	1983	1983	1988
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1300	910	910	910	910	910	910	910	910	910	910	1310
Vendor	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome
A/E	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling												
Date EOL metal available	2037	2030	2030	2031	2031	2035	2035	2031	2033	2033	2033	2038
Quantity of metal (tonnes):												
Aluminum Non-radioactive	95	75	75	75	75	75	75	75	75	75	75	96
Surf. contam.-cleanable	18	14	14	14	14	14	14	14	14	14	14	18
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	6	5	5	5	5	5	5	5	5	5	5	6
Copper Non-radioactive	5837	4601	4601	4601	4601	4601	4601	4601	4601	4601	4601	5866
Surf. contam.-cleanable	95	75	75	75	75	75	75	75	75	75	75	96
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	24	19	19	19	19	19	19	19	19	19	19	24
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	9875	7785	7785	7785	7785	7785	7785	7785	7785	7785	7785	9925
Surf. contam.-cleanable	7981	6292	6292	6292	6292	6292	6292	6292	6292	6292	6292	8022
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3502	2761	2761	2761	2761	2761	2761	2761	2761	2761	2761	3520
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1072	845	845	845	845	845	845	845	845	845	845	1078
Surf. contam.-non-clnbl	357	282	282	282	282	282	282	282	282	282	282	359
Activated	798	629	629	629	629	629	629	629	629	629	629	802
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

France

	Nogent 2	Paluel 1	Paluel 2	Paluel 3	Paluel 4	Saint Alban 1	Saint Alban 2	St Laurent B1	St Laurent B2	Tricastin 1	Tricastin 2	Tricastin 3
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	615FP	554FP	585FP	588FP	589FP	611FP	612FP	550FP	552FP	503FP	505FP	420FP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	France	France	France	France	France	France	France	France	France	France	France	France
Start of operations	1989	1985	1985	1986	1986	1986	1987	1983	1983	1980	1980	1981
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1310	1330	1330	1330	1330	1335	1335	880	880	915	915	915
Vendor	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome	Framatome
A/E	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF	EdF
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling										River	River	River
Date EOL metal available	2039	2035	2035	2036	2036	2036	2037	2033	2033	2030	2030	2031
Quantity of metal (tonnes):												
Aluminum Non-radioactive	96	97	97	97	97	97	97	73	73	75	75	75
Surf. contam.-cleanable	18	18	18	18	18	18	18	14	14	14	14	14
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	6	6	6	6	6	6	6	5	5	5	5	5
Copper Non-radioactive	5866	5926	5926	5926	5926	5941	5941	4500	4500	4618	4618	4618
Surf. contam.-cleanable	96	97	97	97	97	97	97	73	73	75	75	75
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	24	24	24	24	24	24	24	18	18	19	19	19
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	9925	10026	10026	10026	10026	10051	10051	7613	7613	7813	7813	7813
Surf. contam.-cleanable	8022	8103	8103	8103	8103	8123	8123	6153	6153	6315	6315	6315
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3520	3556	3556	3556	3556	3565	3565	2700	2700	2771	2771	2771
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1078	1088	1088	1088	1088	1091	1091	826	826	848	848	848
Surf. contam.-non-clnbl	359	363	363	363	363	364	364	275	275	283	283	283
Activated	802	810	810	810	810	812	812	615	615	631	631	631
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

France

	Tricastin 4	Bugey 1	Chinon A2	Chinon A3	St Laurent A1	St Laurent A2	Phenix	Super Phenix 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	421FP	139FG	50FG	81FG	97FG	138FG	210FF	357FF
Plant type	PWR	Magnox III	Magnox I	Magnox III	Magnox III	Magnox III	LMR	LMR
Location	France	France	France	France	France	France	France	France
Start of operations	1981	1972	1965	1967	1969	1971	1974	1986
Status	Operating	Operating	Shut down	Shut down	Shut down	Shut down	Operating	Operating
Size (MWe) (Net)	915	540	180	360	390	450	233	1200
Vendor	Framatome	Various	Various	Various	Various	Various	CEA/EdF/GAAA	Nvtme/Nira
A/E	EdF	EdF	EdF/CEA	EdF/CEA	EdF	EdF	CEA/GAAA/EdF	Nersa
Pre or Post TMI	Post	Pre	Pre	Pre	Pre	Pre	Pre	Post
No. of steam turbines	1	2	2	2	2	2	1	
Cooling	River							
Date EOL metal available	2031	2022	2015	2017	2019	2021	2024	2036
Quantity of metal (tonnes):								
Aluminum Non-radioactive	75	80	0	80	80	80		
Surf. contam.-cleanable	14	15	0	15	15	15		
Surf. contam.-non-clnbl	0	0	0	0	0	0		
Activated	5	5	0	5	5	5		
Copper Non-radioactive	4618	3900	1900	3900	3900	3900		
Surf. contam.-cleanable	75	80	50	80	80	80		
Surf. contam.-non-clnbl	0	0	0	0	0	0		
Activated	19	20	50	20	20	20		
Lead Non-radioactive	20	20	0	20	20	20		
Surf. contam.-cleanable	0	0	0	0	0	0		
Surf. contam.-non-clnbl	0	0	0	0	0	0		
Activated	0	0	0	0	0	0		
Steel & Iron Non-radioactive	7813	12770	3800	12770	12770	12770		
Surf. contam.-cleanable	6315	5630	4950	5630	5630	5630		
Surf. contam.-non-clnbl	0	0	0	0	0	0		
Activated	2771	2100	1000	2100	2100	2100		
St. Steel Non-radioactive	0	60	100	60	60	60		
Surf. contam.-cleanable	848	900	0	900	900	900		
Surf. contam.-non-clnbl	283	0	0	0	0	0		
Activated	631	165	0	165	165	165		
Zirconium Non-radioactive	0	0	0	0	0	0		
Surf. contam.-cleanable	0	0	0	0	0	0		
Surf. contam.-non-clnbl	0	0	0	0	0	0		
Activated	0	0	0	0	0	0		

Germany

	Brunsbuettel KKB	Gundremmingen A	Gundremmingen B	Gundremmingen C	Isar KKI 1	Kahl VAK	Kruemmel KKK	Lingen KWL	Philippsburg 1	Wuergassen KWW	Biblis A	Biblis B
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	274DB	91DB	522DB	526DB	339DB	62DB	385DB	110DB	341DB	214DB	273DB	338DB
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	PWR	PWR
Location	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR
Start of operations	1977	1967	1984	1985	1979	1962	1984	1968	1980	1975	1875	1977
Status	Operating	Shut down	Operating	Operating	Operating	Shut down	Operating	Shut down	Operating	Operating	Operating	Operating
Size (MWe) (Net)	771	237	1240	1248	870	15	1260	256	864	640	1146	1240
Vendor	KWU	GE/Ruhrst.	KWU		KWU	GE	KWU	AEG	KWR/AEG	AEG	Siemens	Siemens
A/E	KWU	AEG/Hochtief	KWU	KWU	KWU	AEG	KWU	AEG/Hochtief	KWU	Siemens	KWU	KWU
Pre or Post TMI	Pre	Pre	Post	Post	Pre	Pre	Post	Pre	Post	Pre	Pre	Pre
No. of steam turbines	1	1	1	2	1	1	1	1	1	1	1	1
Cooling	River		Tower	Tower	River		River		River		Rvr/twr	Rvr/twr
Date EOL metal available	2027	2017	2034	2035	2029	2012	2034	2018	2030	2025	1925	2027
Quantity of metal (tonnes):												
Aluminum Non-radioactive	67	31	92	93	73	5	93	32	73	59	88	92
Surf. contam.-cleanable	13	6	17	17	14	1	17	6	14	11	16	17
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	4	2	6	6	5	0	6	2	5	4	5	6
Copper Non-radioactive	4120	1877	5656	5680	4466	298	5716	1976	4445	3639	5366	5656
Surf. contam.-cleanable	67	31	92	93	73	5	93	32	73	59	88	92
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	17	8	23	23	18	1	23	8	18	15	22	23
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	4204	1915	5771	5796	4557	304	5833	2016	4536	3713	9078	9568
Surf. contam.-cleanable	5633	2566	7733	7766	6106	408	7816	2701	6078	4976	7337	7733
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2943	1340	4040	4057	3190	213	4083	1411	3175	2599	3220	3393
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	504	230	693	695	547	36	700	242	544	446	986	1039
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	329	346
Activated	563	257	773	777	611	41	782	270	608	498	734	773
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Germany

	Brokdorf	Emsland KKE	Grafen-rheinfeld	Grohnde	Isar KKI 2	Muelheim-Kaerlich	Neckar GKN 1	Neckar GKN 2	Obrigheim KWO	Phillips-burg 2	Stade KKS	THTR 300 Uentrop
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	525DB	683DP	524DB	563DP	651DP	449DB	337DB	682DP	142DB	567DP	215DB	307DG
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	HTGR
Location	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR	Germany,FR
Start of operations	1986	1988	1982	1985	1988	1987	1976	1990	1969	1985	1972	1987
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Shut down
Size (MWe) (Net)	1290	1264	1235	1300	1310	1219	795	1225	340	1268	640	296
Vendor	KWU	KWU	KWU	KWU	KWU	BBR	Siemens	KWU	Siemens	KWU	Siemens	HRB
A/E	KWU	KWU	KWU	KWU	KWU	BBC/BBR	KWU	KWU	Siemens	KWU	AEG	BBC/HRB
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Pre	Post	Pre	Post	Pre	Post
No. of steam turbines	1	1	1	1	1	1	2	1	1	1	1	1
Cooling		Tower	Tower	River	Tower	Tower	Fr. wtr twr	Tower	River	River		Nat. drft dry t
Date EOL metal available	2036	2038	2032	2035	2038	2037	2026	2040	2019	2035	2022	2037
Quantity of metal (tonnes):												
Aluminum Non-radioactive	95	94	92	95	96	91	69	92	39	94	59	80
Surf. contam.-cleanable	18	18	17	18	18	17	13	17	7	18	11	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	6	6	6	6	6	6	4	6	2	6	4	5
Copper Non-radioactive	5807	5728	5640	5837	5866	5592	4205	5610	2387	5740	3639	3900
Surf. contam.-cleanable	95	94	92	95	96	91	69	92	39	94	59	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	24	23	23	24	24	23	17	23	10	23	15	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	9824	9691	9543	9875	9925	9460	7114	9491	4038	9712	6157	12770
Surf. contam.-cleanable	7940	7833	7712	7981	8022	7646	5750	7671	3264	7849	4976	5630
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3484	3437	3384	3502	3520	3355	2523	3366	1432	3444	2183	2100
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	60
Surf. contam.-cleanable	1067	1052	1036	1072	1078	1027	772	1030	438	1054	668	900
Surf. contam.-non-clnbl	356	351	345	357	359	342	257	343	146	351	223	0
Activated	794	783	771	798	802	765	575	767	326	785	498	165
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Germany

	Unterwe-ser fKKU	Greifswald 1 (Lubmin)	Greifswald 2 (Lubmin)	Greifswald 3 (Lubmin)	Greifswald 4 (Lubmin)	Greifswald 5 (Lubmin)	Greifswald 6 (Lubmin)	Greifswald 7 (Lubmin)	Greifswald 8 (Lubmin)	Stendal 1	Stendal 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	340DB	174DDRP	218DDRP	389DDRP	390DDRP	622DDRP	623DDRP	624DRP	625DDRP	705DDRP	706DDRP
Plant type	PWR	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	Germany,FR	Germany,DR	Germany,DR	Germany,DR	Germany,DR	Germany,DR	Germany,DR	Germany,DR	Germany,DR	Germany,DR	Germany,DR
Start of operations	1979	1974	1975	1978	1979	1990					
Status	Operating	Shut down	Shut down	Shut down	Shut down	Shut down	Operating	Under Const	Under Const	Under Const	Under Const
Size (MWe) (Net)	1230	440	440	440	440	440	440	440	440	1000	1000
Vendor	KWU	AEE	AEE	AEE	AEE	AEE	AEE	AEE	AEE	AEE	AEE
A/E	KWU					TEP/KKAB	TEP/KKAB	TEP/KKAB	TEP/KKAB	TEP/KKAB	TEP/KKAB
Pre or Post TMI	Pre	Pre	Pre	Pre	Pre	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	2	2	2	2	2	2	2	2	1	1
Cooling	wr									Tower	Tower
Date EOL metal available	2029	2024	2025	2028	2029	2040	2053	2053	2053	2053	2053
Quantity of metal (tonnes):											
Aluminum Non-radioactive	92	46	46	46	46	46	46	46	46	80	80
Surf. contam.-cleanable	17	9	9	9	9	9	9	9	9	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0
Activated	6	3	3	3	3	3	3	3	3	5	5
Copper Non-radioactive	5625	2840	2840	2840	2840	2840	2840	2840	2840	4900	4900
Surf. contam.-cleanable	92	46	46	46	46	46	46	46	46	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0
Activated	23	12	12	12	12	12	12	12	12	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	9517	12030	12030	12030	12030	12030	12030	12030	12030	19248	19248
Surf. contam.-cleanable	7692	4669	4669	4669	4669	4669	4669	4669	4669	7156	7156
Surf. contam.-non-clnbl	0	46	46	46	46	46	46	46	46	69	69
Activated	3375	363	363	363	363	363	363	363	363	581	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1033	1599	1599	1599	1599	1599	1599	1599	1599	2600	2600
Surf. contam.-non-clnbl	344	0	0	0	0	0	0	0	0	0	0
Activated	769	254	254	254	254	254	254	254	254	406	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0

U.K.

	Dungeness B1	Dungeness B2	Hartlepool 1	Hartlepool 2	Heysham 1-1	Heysham 1-2	Heysham 2-1	Heysham 2-2	Hinkley Point B1	Hinkley Point B2	Hunter-ston B1	Hunter-ston B2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	116GBG	117GBG	180GBG	181GBG	182GBG	183GBG	641GBG	642GBG	175GBG	177GBG	178GBG	179GBG
Plant type	AGR	AGR	AGR	AGR	AGR	AGR	AGR	AGR	AGR	AGR	AGR	AGR
Location	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK
Start of operations	1985	1988	1984	1985	1984	1985	1988	1989	1978	1976	1976	1977
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	600	600	625	625	625	625	615	615	625	625	624	624
Vendor	APC	APC	NNC	NNC	NNC	NNC	NNC	NNC	TNPG	TNPG	TNPG	TNPG
A/E	APC	APC	NNC	NNC	NNC	NNC	NNC	NNC	TNPG	TNPG	TNPG	TNPG
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Pre	Pre	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling												
Date EOL metal available	2035	2038	2034	2035	2034	2035	2038	2039	2028	2026	2026	2027
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	80	80	80	80	80	80	80	80
Surf. contam.-cleanable	15	15	15	15	15	15	15	15	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	5	5	5	5	5	5	5
Copper Non-radioactive	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900	3900
Surf. contam.-cleanable	80	80	80	80	80	80	80	80	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	20	20	20	20	20	20	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12770	12770	12770	12770	12770	12770	12770	12770	12770	12770	12770	12770
Surf. contam.-cleanable	5630	5630	5630	5630	5630	5630	5630	5630	5630	5630	5630	5630
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100
St. Steel Non-radioactive	60	60	60	60	60	60	60	60	60	60	60	60
Surf. contam.-cleanable	900	900	900	900	900	900	900	900	900	900	900	900
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	165	165	165	165	165	165	165	165	165	165	165	165
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.K.

	Torness 1	Torness 2	Berkeley 1	Berkeley 2	Bradwell 1	Bradwell 2	Dungeness A1	Dungeness A2	Hinkley Point A1	Hinkley Point A2	Hunterston A1	Hunterston A2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	639GBG	640GBG	39GBG	40GBG	41GBG	42GBG	75GBG	76GBG	52GBG	53GBG	43GBG	44GBG
Plant type	AGR	AGR	Magnox I	Magnox I	Magnox I	Magnox I	Magnox II	Magnox II	Magnox II	Magnox II	Magnox II	Magnox II
Location	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK
Start of operations	1988	1989	1962	1962	1962	1962	1965	1965	1965	1965	1962	1964
Status	Operating	Operating	Shut down	Shut down	Operating	Operating	Operating	Operating	Operating	Operating	Shut down	Shut down
Size (MWe) (Net)	625	625	138	138	150	150	275	275	250	250	150	150
Vendor	NNC	NNC	TNPG	TNPG	TNPG	TNPG	TNPG	TNPG	EE/BW/TW	EE/BW/TW	GEC	GEC
A/E	NNC	NNC	TNPG	TNPG	TNPG	TNPG	TNPG	TNPG	EE/BW/TW	EE/BW/TW		
Pre or Post TMI	Post	Post	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Pre
No. of steam turbines	1	1	4	4	3	3	2	2	3	3	3	3
Cooling												
Date EOL metal available	2038	2039	2012	2012	2012	2012	2015	2015	2015	2015	2012	2014
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	15	15	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	0	0	0	0	0	0	0	0	0	0
Copper Non-radioactive	3900	3900	1900	1900	1900	1900	2400	2400	2400	2400	2400	2400
Surf. contam.-cleanable	80	80	50	50	50	50	50	50	50	50	50	50
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	50	50	50	50	50	50	50	50	50	50
Lead Non-radioactive	20	20	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12770	12770	3800	3800	3800	3800	4690	4690	4690	4690	4690	4690
Surf. contam.-cleanable	5630	5630	4950	4950	4950	4950	6225	6225	6225	6225	6225	6225
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2100	2100	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
St. Steel Non-radioactive	60	60	100	100	100	100	100	100	100	100	100	100
Surf. contam.-cleanable	900	900	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	165	165	0	0	0	0	0	0	0	0	0	0
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

U.K.	Oldbury 1	Oldbury 2	Sizewell A1	Sizewell A2	Trawsfynydd 1	Trawsfynydd 2	Wylfa A1	Wylfa A2	Dounreay PFR	Sizewell B
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	87GBG	88GBG	82BGB	83GBG	64GBG	65GBG	102GBG	103GBG	145GBF	733GBP
Plant type	Magnox III	Magnox III	Magnox II	Magnox I	Magnox II	Magnox II	Magnox III	Magnox III	LMR	PWR
Location	UK	UK	UK	UK	UK	UK	UK	UK	UK	UK
Start of operations	1966	1968	1965	1966	1965	1965	1971	1972	1976	
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Under Const
Size (MWe) (Net)	300	300	290	290	250	250	590	590	250	1188
Vendor	TNPG	TNPG	EE/BW/TW	EE/BW/TW	APC	APC	EE/BW/TW	EE/BW/TW	UKAEA/TNPG	Westinghouse
A/E	TNPG	TNPG	EE/BW/TW	EE/BW/TW	APC	APC	EE/BW/TW	EE/BW/TW	AEA Tch./TNPG	
Pre or Post TMI	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Pre	Post
No. of steam turbines	1	1	1	1	2	2	2	2	1	1
Cooling			Nuc Elec						Sea	
Date EOL metal available	2016	2018	2015	2016	2015	2015	2021	2022	2026	2053
Quantity of metal (tonnes):										
Aluminum Non-radioactive	80	80	0	0	0	0	80	80		90
Surf. contam.-cleanable	15	15	0	0	0	0	15	15		17
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0		0
Activated	5	5	0	0	0	0	5	5		6
Copper Non-radioactive	3900	3900	2400	1900	2400	2400	3900	3900		5496
Surf. contam.-cleanable	80	80	50	50	50	50	80	80		90
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0		0
Activated	20	20	50	50	50	50	20	20		22
Lead Non-radioactive	20	20	0	0	0	0	20	20		20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0		0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0		0
Activated	0	0	0	0	0	0	0	0		0
Steel & Iron Non-radioactive	12770	12770	4690	3800	4690	4690	12770	12770		9299
Surf. contam.-cleanable	5630	5630	6225	4950	6225	6225	5630	5630		7515
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0		0
Activated	2100	2100	1000	1000	1000	1000	2100	2100		3298
St. Steel Non-radioactive	60	60	100	100	100	100	60	60		0
Surf. contam.-cleanable	900	900	0	0	0	0	900	900		1010
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0		337
Activated	165	165	0	0	0	0	165	165		752
Zirconium Non-radioactive	0	0	0	0	0	0	0	0		0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0		0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0		0
Activated	0	0	0	0	0	0	0	0		0

Other Europe

	Doel 1	Doel 2	Doel 3	Doel 4	Tihange 1	Tihange 2	Tihange 3	Belene 1	Belene 2	Belene 3	Belene 4	Kozloduy 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	220BP	222BP	482BP	545BP	221BP	483BP	546BP	687BULP	716BULP	768BULP	769BULP	184BULP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	VVER	VVER	VVER	VVER	VVER
Location	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria
Start of operations	1975	1975	1982	1985	1975	1983	1985			1998	2000	1974
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Under Const	Under Const	Planned	Planned	Operating
Size (MWe) (Net)	392	392	900	1010	870	900	1020	953	953	953	953	405
Vendor	Acecowen	Acecowen	Framaceco	Acecowen	Framaceco	Framaceco	Acecowen	AEE	AEE	AEE	AEE	AEE
A/E	Tractebel	Tractebel	Tractebel	Tractebel	Tractebel	Tractebel	Tractebel	SEU/IC	SEU/IC	SEU/IC	SEU/IC	SEU/IC
Pre or Post TMI	Pre	Pre	Post	Post	Pre	Post	Post	Post	Post	Post	Post	Pre
No. of steam turbines	1	1	1	1	2	1	1	1	1	1	1	2
Cooling	Lake	River/tower	River/tower	River/tower	River/tower	River/tower	River/tower					
Date EOL metal available	2025	2025	2032	2035	2025	2033	2035	2053	2053	Unknown	Unknown	2024
Quantity of metal (tonnes):												
Aluminum Non-radioactive	43	43	75	81	73	75	81	80	80	80	80	46
Surf. contam.-cleanable	8	8	14	15	14	14	15	15	15	15	15	9
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	3	5	5	5	5	5	5	5	5	5	3
Copper Non-radioactive	2625	2625	4568	4933	4466	4568	4965	4900	4900	4900	4900	2840
Surf. contam.-cleanable	43	43	75	81	73	75	81	80	80	80	80	46
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	11	11	19	20	18	19	20	20	20	20	20	12
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	4440	4440	7728	8345	7555	7728	8400	19248	19248	19248	19248	12030
Surf. contam.-cleanable	3589	3589	6246	6745	6106	6246	6789	7156	7156	7156	7156	4669
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	69	69	69	69	46
Activated	1575	1575	2741	2960	2679	2741	2979	581	581	581	581	363
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	482	482	839	906	820	839	912	2600	2600	2600	2600	1599
Surf. contam.-non-clnbl	161	161	280	302	273	280	304	0	0	0	0	0
Activated	359	359	625	674	611	625	679	406	406	406	406	254
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Other Europe

	Kozloduy 2	Kozloduy 3	Kozloduy 4	Kozloduy 5	Kozloduy 6	Olkiluoto 1	Olkiluoto 2	Lovilsa 1	Lovilsa 2	Hungary 7	Hungary 8	Hungary 9
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	185BULP	352BULP	353BULP	626BULP	652BULP	355SFB	502SFB	260SFP	322SFP	784HP	785HP	786HP
Plant type	WER	WER	WER	WER	WER	BWR	BWR	PWR	PWR	WER	WER	WER
Location	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Finland	Finland	Finland	Finland	Hungary	Hungary	Hungary
Start of operations	1975	1981	1982	1988	1990	1979	1982	1977	1981			
Status	Operating	Operating	Operating	Operating	Under Const	Operating	Operating	Operating	Operating	Planned	Planned	Planned
Size (MWe) (Net)	405	405	405	953	953	710	710	445	445	953	953	953
Vendor	AEE	AEE	AEE	AEE	AEE	ABB-Atom	ABB-Atom	V-O/AEE	V-O/AEE	AEE/SSSR	AEE/SSSR	AEE/SSSR
A/E	SEU/IC	SEU/IC	SEU/IC	SEU/IC	SEU/IC	ABB Atom	ABB-Atom	AEE	IVO	ERBE	ERBE	ERBE
Pre or Post TMI	Pre	Post	Post	Post	Post	Pre	Post	Pre	Post	Post	Post	Post
No. of steam turbines	1			1	1	1	1	2	2	1	1	1
Cooling						Sea	Sea					
Date EOL metal available	2025	2031	2032	2038	2040	2029	2032	2027	2031	Unknown	Unknown	Unknown
Quantity of metal (tonnes):												
Aluminum Non-radioactive	46	46	46	80	80	64	64	47	47	80	80	80
Surf. contam.-cleanable	9	9	9	15	15	12	12	9	9	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	3	3	5	5	4	4	3	3	5	5	5
Copper Non-radioactive	2840	2840	2840	4900	4900	3900	3900	2856	2856	4900	4900	4900
Surf. contam.-cleanable	46	46	46	80	80	64	64	47	47	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	12	12	20	20	16	16	12	12	20	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12030	12030	12030	19248	19248	3979	3979	4832	4832	19248	19248	19248
Surf. contam.-cleanable	4669	4669	4669	7156	7156	5332	5332	3905	3905	7156	7156	7156
Surf. contam.-non-clnbl	46	46	46	69	69	0	0	0	0	69	69	69
Activated	363	363	363	581	581	2786	2786	1714	1714	581	581	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1599	1599	1599	2600	2600	478	478	525	525	2600	2600	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	175	175	0	0	0
Activated	254	254	254	406	406	533	533	391	391	406	406	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Other Europe

	Paks 1	Paks 2	Paks 3	Paks 4	Paks 5	Paks 6	Caorso	Garigliano	Latina	Trino Vercellese	Borssele	Kujawy 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	346HP	347HP	595HP	596HP	745HP	746HP	252IB	55IB	54IG	32IP	266NLP	811PLP
Plant type	WER	WER	WER	WER	WER	WER	BWR	BWR	Magnox I	PWR	PWR	WER
Location	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Italy	Italy	Italy	Italy	Netherlands	Poland
Start of operations	1983	1984	1986	1987			1981	1964	1964	1965	1973	
Status	Operating	Operating	Operating	Operating	Planned	Planned	Shut down	Shut down	Shut down	Shut down	Operating	Planned
Size (MWe) (Net)	408	408	408	408	953	953	860	150	153	260	452	950
Vendor	AEE/SSSR	AEE/SSSR	AEE/SSSR	AEE/SSSR	AEE/SSSR	AEE/SSSR	AMN/Getsco	GE	TNPG	Wstnghse	KWU	
A/E	ERBE	ERBE	ERBE	ERBE	ERBE	ERBE	Gibbs & Hill	Ebasco	TNPG	Gibbs & Hill	KWU	VO/AEE
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Pre	Pre	Pre	Pre	Post
No. of steam turbines	2	2	2	2	1	1	1	1	3	2	1	1
Cooling	River	River	River	River			River	River	Sea	River	River	
Date EOL metal available	2033	2034	2036	2037	Unknown	Unknown	2031	2014	2014	2015	2023	Unknown
Quantity of metal (tonnes):												
Aluminum Non-radioactive	46	46	46	46	80	80	72	23	0	33	47	80
Surf. contam.-cleanable	9	9	9	9	15	15	14	4	0	6	9	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	3	3	3	5	5	5	1	0	2	3	5
Copper Non-radioactive	2840	2840	2840	2840	4900	4900	4431	1383	1900	1996	2886	4900
Surf. contam.-cleanable	46	46	46	46	80	80	72	23	50	33	47	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	12	12	12	20	20	18	6	50	8	12	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	0	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12030	12030	12030	12030	19248	19248	4522	1412	3800	3377	4883	19248
Surf. contam.-cleanable	4669	4669	4669	4669	7156	7156	6059	1891	4950	2729	3946	7156
Surf. contam.-non-clnbl	46	46	46	46	69	69	0	0	0	0	0	69
Activated	363	363	363	363	581	581	3165	988	1000	1198	1732	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	100	0	0	0
Surf. contam.-cleanable	1599	1599	1599	1599	2600	2600	543	169	0	367	530	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	122	177	0
Activated	254	254	254	254	406	406	606	189	0	273	395	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Other Europe

	Kujawy 2	Kujawy 3	Kujawy 4	Warta 1	Warta 2	Warta 3	Warta 4	Zarnowiec 1	Zarnowiec 2	Zarnowiec 3	Zarnowiec 4	Cernavoda 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	812PLP	813PLP	814PLP	897PLP	898PLP	899PLP	900PLP	506PLP	508PLP	510PLP	511PLP	608RH
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	PHWR
Location	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Romania
Start of operations												
Status	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Under Const	Under Const	Under Const	Under Const	Under Const
Size (MWe) (Net)	950	950	950	950	950	950	950	424	424	424	424	620
Vendor								Skoda/Praha	Skoda/Praha	Skoda/Praha	Skoda/Praha	AECL
A/E	VO/AEE	VO/AEE	VO/AEE	EPW/LOATEP	EPW/LOATEP	EPW/LOATEP	EPW/LOATEP	EPW/LOATEP	EPW/LOATEP	EPW/LOATEP	EPW/LOATEP	Inst.Pwr S&D
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling				Tower	Tower	Tower	Tower	Lake	Lake	Lake	Lake	River
Date EOL metal available	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	2053	2053	2053	2053	2053
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	80	80	80	46	46	46	46	63
Surf. contam.-cleanable	15	15	15	15	15	15	15	9	9	9	9	12
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	5	5	3	3	3	3	4
Copper Non-radioactive	4900	4900	4900	4900	4900	4900	4900	2840	2840	2840	2840	3877
Surf. contam.-cleanable	80	80	80	80	80	80	80	46	46	46	46	63
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	20	20	20	12	12	12	12	16
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	19248	19248	19248	12030	12030	12030	12030	6329
Surf. contam.-cleanable	7156	7156	7156	7156	7156	7156	7156	4669	4669	4669	4669	4747
Surf. contam.-non-clnbl	69	69	69	69	69	69	69	46	46	46	46	0
Activated	581	581	581	581	581	581	581	363	363	363	363	2326
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	229
Surf. contam.-cleanable	2600	2600	2600	2600	2600	2600	2600	1599	1599	1599	1599	1582
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	158
Activated	406	406	406	406	406	406	406	254	254	254	254	1661
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	25

Other Europe

	Cernavoda 2	Cernavoda 3	Cernavoda 4	Cernavoda 5	Cofrentes	Santa Maria de Garnoa	Vandellos 1	Almaraz 1	Almaraz 2	Asco 1	Asco 2	Jose Cabrera
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	662RH	704RH	708RH	722RH	428EB	141EB	171EG	328EP	362EP	363EP	429EP	133EP
Plant type	PHWR	PHWR	PHWR	PHWR	BWR	BWR	Magnox III	PWR	PWR	PWR	PWR	PWR
Location	Romania	Romania	Romania	Romania	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain
Start of operations					1985	1971	1972	1981	1984	1984	1986	1969
Status	Under Const	Under Const	Under Const	Under Const	Operating	Operating	Shut down	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	620	620	620	620	958	440	480	900	902	887	887	153
Vendor	AECL	MICM	MICM	MICM	GE	GE	CEA/SFAC	Westinghouse	Westinghouse	Westinghouse	Westinghouse	Westinghouse
A/E	Inst.Pwr S&D	Inst.Pwr S&D	Inst.Pwr S&D	Inst.Pwr S&D	E. A./G&H	Ebasco	Socia			Bechtel, etc.	Bechtel, etc.	Gibbs & Hill
Pre or Post TMI	Post	Post	Post	Post	Post	Pre	Pre	Post	Post	Post	Post	Pre
No. of steam turbines	1	1	1	1	1	1	2	1	1	1	1	1
Cooling	River	River	River	River	Tower	River						
Date EOL metal available	2053	2053	2053	2053	2035	2021	2022	2031	2034	2034	2036	2019
Quantity of metal (tonnes):												
Aluminum Non-radioactive	63	63	63	63	78	46	80	75	75	74	74	23
Surf. contam.-cleanable	12	12	12	12	15	9	15	14	14	14	14	4
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	4	4	4	4	5	3	5	5	5	5	5	1
Copper Non-radioactive	3877	3877	3877	3877	4762	2835	3900	4568	4574	4524	4524	1402
Surf. contam.-cleanable	63	63	63	63	78	46	80	75	75	74	74	23
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	16	16	16	16	19	12	20	19	19	18	18	6
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	6329	6329	6329	6329	4859	2892	12770	7728	7739	7653	7653	2371
Surf. contam.-cleanable	4747	4747	4747	4747	6511	3876	5630	6246	6255	6185	6185	1917
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2326	2326	2326	2326	3401	2025	2100	2741	2745	2714	2714	841
St. Steel Non-radioactive	229	229	229	229	0	0	60	0	0	0	0	0
Surf. contam.-cleanable	1582	1582	1582	1582	583	347	900	839	840	831	831	257
Surf. contam.-non-clnbl	158	158	158	158	0	0	0	280	280	277	277	86
Activated	1661	1661	1661	1661	651	388	165	625	625	619	619	192
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	25	25	25	25	0	0	0	0	0	0	0	0

Other Europe

	Trillo 1	Vandellos 2	Barsebaeck 1	Barsebaeck 2	Forsmark 1	Forsmark 2	Forsmark 3	Oskar-shamn 1	Oskar-shamn 2	Oskar-shamn 3	Ringhals 1	Ringhals 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	560EP	558EP	267SB	450SB	342SB	277SB	565SB	143SB	275SB	581SB	248SB	249SP
Plant type	PWR	PWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	PWR
Location	Spain	Spain	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden
Start of operations	1989	1988	1975	1977	980	1981	1985	1972	1974	1985	1976	1975
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	991	951	600	585	970	970	1050	440	595	1160	750	800
Vendor	KWU	Westinghouse	Asea-Atom	Asea-Atom	Asea-Atom	Asea-Atom	Asea-Atom	ABB-Atom	ABB-Atom	ABB-Atom	Asea-Atom	Westinghouse
A/E		Initec/Bechte	VBB	VBB	SSPB	SSPB	SSPB		VBB		A-A/SSPB	SSPB/G&H
Pre or Post TMI	Post	Post	Pre	Pre	Pre	Post	Post	Pre	Pre	Post	Pre	Pre
No. of steam turbines	1	1	1	1	2	2	1	1	1	1	2	2
Cooling		Sea										
Date EOL metal available	2039	2038	2025	2027	1030	2031	2035	2022	2024	2035	2026	2025
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	77	57	56	78	78	83	46	57	88	66	69
Surf. contam.-cleanable	15	15	11	10	15	15	15	9	11	17	12	13
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	4	3	5	5	5	3	4	6	4	4
Copper Non-radioactive	4871	4739	3486	3427	4802	4802	5062	2835	3466	5410	4045	4223
Surf. contam.-cleanable	80	77	57	56	78	78	83	46	57	88	66	69
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	19	14	14	20	20	21	12	14	22	17	17
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	8240	8017	3557	3497	4899	4899	5165	2892	3537	5520	4127	7144
Surf. contam.-cleanable	6660	6479	4766	4686	6565	6565	6922	3876	4740	7397	5531	5774
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2922	2843	2490	2448	3430	3430	3616	2025	2476	3864	2889	2534
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	895	870	427	420	588	588	620	347	424	662	495	776
Surf. contam.-non-clnbl	298	290	0	0	0	0	0	0	0	0	0	259
Activated	666	648	477	469	657	657	692	388	474	740	553	577
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Other Europe

	Ringhals 3	Ringhals 4	Leibstadt	Muehle-berg 1	Beznau	Beznau CNL	Goesgen 2	Sinop	Akkuyu 1	Akkuyu 2	Krsko	Previaka
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	381SP	382SP	4757CHB	173CHB	217CHP	144CHP	455CHP	871TRB	752TRH	753TRP	412YUP	862YUP
Plant type	PWR	PWR	BWR	BWR	PWR	PWR	PWR	BWR	PHWR	PWR	PWR	VVER
Location	Sweden	Sweden	Switzerland	Switzerland	Switzerland	Switzerland	Switzerland	Turkey	Turkey	Turkey	Slovenia	Slovenia
Start of operations	1981	983	1984	1972	1972	1989	1979					
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Planned	Planned	Planned	Operating	Planned
Size (MWe) (Net)	915	915	990	320	264	350	920	1200	600	950	632	900
Vendor	Westinghouse	Westinghouse	Getsco	Getsco	Westinghouse	Westinghouse	KWU				Westinghouse	
A/E	SSPB	SSPB	BBC/Elctrwtt	BBC/E&B/Ge	G&H/BBC	G&H/BBC	KWU				Gilbert	
Pre or Post TMI	Post	Pre	Post	Pre	Pre	Post	Pre	Post	Post	Post	Post	Post
No. of steam turbines	2	2	1	2	2	2	1	1	1	1	1	1
Cooling	Sea	Sea	Nat drft twr	River			Tower					Forced circ.
Date EOL metal available	2031	1033	2034	2022	2022	2039	2029	Unknown	Unknown	Unknown	2053	Unknown
Quantity of metal (tonnes):												
Aluminum Non-radioactive	75	75	79	37	33	40	76	90	62	77	59	80
Surf. contam.-cleanable	14	14	15	7	6	7	14	17	12	14	11	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	2	2	2	5	6	4	5	4	5
Copper Non-radioactive	4618	4618	4867	2292	2017	2434	4635	5533	3793	4735	3609	4900
Surf. contam.-cleanable	75	75	79	37	33	40	76	90	62	77	59	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	19	19	20	9	8	10	19	23	15	19	15	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	7813	7813	4967	2339	3412	4117	7842	5646	6193	8011	6105	19248
Surf. contam.-cleanable	6315	6315	6655	3135	2757	3328	6338	7566	4644	6475	4934	7156
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	69
Activated	2771	2771	3477	1637	1210	1460	2781	3952	2276	2841	2165	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	224	0	0	0
Surf. contam.-cleanable	848	848	596	281	370	447	851	678	1548	870	663	2600
Surf. contam.-non-clnbl	283	283	0	0	123	149	284	0	155	290	221	0
Activated	631	631	666	313	276	333	634	757	1626	647	493	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	25	0	0	0

FSU

	Beloyar-skiy 3	Beloyar-skiy 4	BN 350	South Urals 1	South Urals 2	Beloyarsk 1	Beloyarsk 2	Chernobyl 1	Chernobyl 2	Chernobyl 3	Chernobyl 4	Ignalina 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	230SUF	738SUF	93SUF	907SUF	928SUF	57SUG	71SUG	313SUG	314SUG	498SUG	499SUG	495SUG
Plant type	LMR	LMR	LMR	LMR	LMR	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK
Location	Russia	Russia	Kazakhstan	Russia	Russia	Russia	Russia	Ukraine	Ukraine	Ukraine	Ukraine	Lithuania
Start of operations	1980		1973			1964	1969	1978	1979	1982	1984	1985
Status	Operating	Under Const	Operating	Planned	Planned	Shut down	Shut down	Operating	Shut down	Operating	Shut down	Operating
Size (MWe) (Net)	560	750	135	760	750	102	146	925	925	925	925	1370
Vendor	MTM						MTP	MTP	MTP	MTP	MTP	MTP
A/E	AEP	AEP		AEP	AEP		AEP	AEP	AEP	AEP	AEP	NIPIET
Pre or Post TMI	Post	Post	Pre	Post	Post	Pre	Pre	Pre	Pre	Post	Post	Post
No. of steam turbines	3		3			1	2	2	2	2	2	2
Cooling												
Date EOL metal available	2030	2053	2023	Unknown	Unknown	2014	2019	2028	2029	2032	2034	2035
Quantity of metal (tonnes):												
Aluminum Non-radioactive						80	80	80	80	80	80	80
Surf. contam.-cleanable						15	15	15	15	15	15	15
Surf. contam.-non-clnbl						0	0	0	0	0	0	0
Activated						5	5	5	5	5	5	5
Copper Non-radioactive						4900	4900	4900	4900	4900	4900	4900
Surf. contam.-cleanable						80	80	80	80	80	80	80
Surf. contam.-non-clnbl						0	0	0	0	0	0	0
Activated						20	20	20	20	20	20	20
Lead Non-radioactive						0	0	0	0	0	0	0
Surf. contam.-cleanable						0	0	0	0	0	0	0
Surf. contam.-non-clnbl						0	0	0	0	0	0	0
Activated						0	0	0	0	0	0	0
Steel & Iron Non-radioactive						19248	19248	19248	19248	19248	19248	19248
Surf. contam.-cleanable						7156	7156	7156	7156	7156	7156	7156
Surf. contam.-non-clnbl						69	69	69	69	69	69	69
Activated						581	581	581	581	581	581	581
St. Steel Non-radioactive						0	0	0	0	0	0	0
Surf. contam.-cleanable						2600	2600	2600	2600	2600	2600	2600
Surf. contam.-non-clnbl						0	0	0	0	0	0	0
Activated						406	406	406	406	406	406	406
Zirconium Non-radioactive						0	0	0	0	0	0	0
Surf. contam.-cleanable						0	0	0	0	0	0	0
Surf. contam.-non-clnbl						0	0	0	0	0	0	0
Activated						100	100	100	100	100	100	100

FSU

	Ignalina 2	Kursk 1	Kursk 2	Kursk 3	Kursk 4	Leningrad 1	Leningrad 2	Leningrad 3	Leningrad 4	Smolensk 1	Smolensk 2	Smolensk 3
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	496SUG	232SUG	235SUG	235SUG	501SUG	231SUG	234SUG	548SUG	549SUG	311SUG	312SUG	667SUG
Plant type	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK	RBMK
Location	Lithuania	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia
Start of operations	1987	1977	1979	1984	1986	1974	1976	1980	1981	1983	1985	1990
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	1370	925	925	925	925	925	925	925	925	925	925	925
Vendor	MTP	MTP	MTP	MTP	MTP	MTP	MTP	MTP	MTP	MTP	MTP	MTP
A/E	NIPIET	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP
Pre or Post TMI	Post	Pre	Pre	Post	Post	Pre	Pre	Post	Post	Post	Post	Post
No. of steam turbines	2	2	2	2	2	2	2	2	2	2	2	2
Cooling												
Date EOL metal available	2037	2027	2029	2034	2036	2024	2026	2030	2031	2033	2035	2040
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	80	80	80	80	80	80	80	80
Surf. contam.-cleanable	15	15	15	15	15	15	15	15	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	5	5	5	5	5	5	5
Copper Non-radioactive	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900
Surf. contam.-cleanable	80	80	80	80	80	80	80	80	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	20	20	20	20	20	20	20	20
Lead Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	19248	19248	19248	19248	19248	19248	19248	19248
Surf. contam.-cleanable	7156	7156	7156	7156	7156	7156	7156	7156	7156	7156	7156	7156
Surf. contam.-non-clnbl	69	69	69	69	69	69	69	69	69	69	69	69
Activated	581	581	581	581	581	581	581	581	581	581	581	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	2600	2600	2600	2600	2600	2600	2600	2600	2600	2600	2600	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	406	406	406	406	406	406	406	406	406	406	406	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	100	100	100	100	100	100	100	100	100	100	100	100

FSU

	Aktash 1	Aktash 2	Arkhan-gelsk 1	Arkhan-gelsk 2	Armenia 1	Armenia 2	Balakovo 1	Balakovo 2	Balakovo 3	Balakovo 4	Balakovo 5	Balakovo 6
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	603SUP	644SUP	759SUP	760SUP	233SUP	258SUP	604SUP	678SUP	699SUP	763SUP	764SUP	765SUP
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	FSU	FSU	Russia	Russia	Armenia	Armenia	Russia	Russia	Russia	Russia	Russia	Russia
Start of operations					1976	1980	1986	1988	1990			
Status	Under Const	Under Const	Planned	Planned	Shut down	Shut down	Operating	Operating	Operating	Under Const	Under Const	Under Const
Size (MWe) (Net)	953	953	950	950	376	376	950	950	950	950	950	950
Vendor					MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM
A/E	AEP	AEP			AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP
Pre or Post TMI	Post	Post	Post	Post	Pre	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	2	2	1	1	1	1	1	1
Cooling												
Date EOL metal available	2053	2053	Unknown	Unknown	2026	2030	2036	2038	2040	2053	2053	2053
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	46	46	80	80	80	80	80	80
Surf. contam.-cleanable	15	15	15	15	9	9	15	15	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	3	3	5	5	5	5	5	5
Copper Non-radioactive	4900	4900	4900	4900	2840	2840	4900	4900	4900	4900	4900	4900
Surf. contam.-cleanable	80	80	80	80	46	46	80	80	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	12	12	20	20	20	20	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	12030	12030	19248	19248	19248	19248	19248	19248
Surf. contam.-cleanable	7156	7156	7156	7156	4669	4669	7156	7156	7156	7156	7156	7156
Surf. contam.-non-clnbl	69	69	69	69	46	46	69	69	69	69	69	69
Activated	581	581	581	581	363	363	581	581	581	581	581	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	2600	2600	2600	2600	1599	1599	2600	2600	2600	2600	2600	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	406	406	406	406	254	254	406	406	406	406	406	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

FSU

	Bryansk 1	Kalinin 1	Kalinin 2	Kalinin 3	Kalinin 4	Khmel'nitskiy 2	Khmel'nitskiy 3	Khmel'nitskiy 1	Khmel'nitskiy 4	Kola 1	Kola 2	Kola 3
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	915SUP	317SUP	318SUP	802SUP	803SUP	627SUP	688SUP	573SUP	726SUP	148SUP	149SUP	493SUP
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	FSU	Russia	Russia	Russia	Russia	Ukraine	Ukraine	Ukraine	Ukraine	Russia	Russia	Russia
Start of operations		1985	1987							1973	1973	1982
Status	Planned	Operating	Operating	Under Const	Under Const	Under Const	Under Const	Operating	Under Const	Operating	Operating	Operating
Size (MWe) (Net)	950	950	950	950	950	950	950	950	950	411	411	411
Vendor		MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM
A/E		AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Pre	Pre	Post
No. of steam turbines	2	1	1	1	1	1	1	1	1	2	2	2
Cooling												
Date EOL metal available	Unknown	2035	2037	2053	2053	2053	2053	2053	2053	2023	2023	2032
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	80	80	80	80	80	46	46	46
Surf. contam.-cleanable	15	15	15	15	15	15	15	15	15	9	9	9
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	5	5	5	5	3	3	3
Copper Non-radioactive	4900	4900	4900	4900	4900	4900	4900	4900	4900	2840	2840	2840
Surf. contam.-cleanable	80	80	80	80	80	80	80	80	80	46	46	46
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	20	20	20	20	20	12	12	12
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	19248	19248	19248	19248	19248	12030	12030	12030
Surf. contam.-cleanable	7156	7156	7156	7156	7156	7156	7156	7156	7156	4669	4669	4669
Surf. contam.-non-clnbl	69	69	69	69	69	69	69	69	69	46	46	46
Activated	581	581	581	581	581	581	581	581	581	363	363	363
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	2600	2600	2600	2600	2600	2600	2600	2600	2600	1599	1599	1599
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	406	406	406	406	406	406	406	406	406	254	254	254
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

FSU

	Kola 4	Kola 5	Kola 6	Kostroma 1	Kostroma 2	Kostroma 3	Kostroma 4	Novovoro-nezh 1	Novovoro-nezh 2	Novovoro-nezh 3	Novovoro-nezh 4	Novovoro-nezh 5
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	494SUP	926SUP	927SUP	659SUP	690SUP	736SUP	737SUP	69SUP	106SUP	121SUP	123SUP	256SUP
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia
Start of operations	1984							1964	1970	1972	1973	1981
Status	Operating	Planned	Planned	Under Const	Under Const	Under Const	Under Const	Shut down	Shut down	Operating	Operating	Operating
Size (MWe) (Net)	411	950	950	950	950	950	950	200	336	385	385	950
Vendor	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM
A/E	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Pre	Pre	Pre	Pre	Post
No. of steam turbines	2			1	1	1	1	1	5	2	2	2
Cooling												
Date EOL metal available	2034	Unknown	Unknown	2053	2053	2053	2053	2014	2020	2022	2023	2031
Quantity of metal (tonnes):												
Aluminum Non-radioactive	46	80	80	80	80	80	80	46	46	46	46	80
Surf. contam.-cleanable	9	15	15	15	15	15	15	9	9	9	9	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	5	5	5	5	5	5	3	3	3	3	5
Copper Non-radioactive	2840	4900	4900	4900	4900	4900	4900	2840	2840	2840	2840	4900
Surf. contam.-cleanable	46	80	80	80	80	80	80	46	46	46	46	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	20	20	20	20	20	20	12	12	12	12	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12030	19248	19248	19248	19248	19248	19248	12030	12030	12030	12030	19248
Surf. contam.-cleanable	4669	7156	7156	7156	7156	7156	7156	4669	4669	4669	4669	7156
Surf. contam.-non-clnbl	46	69	69	69	69	69	69	46	46	46	46	69
Activated	363	581	581	581	581	581	581	363	363	363	363	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1599	2600	2600	2600	2600	2600	2600	1599	1599	1599	1599	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	254	406	406	406	406	406	406	254	254	254	254	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

FSU

	Rostov 1	Rostov 2	Rostov 3	Rostov 4	Rovno 1	Rovno 2	Rovno 3	Rovno 4	South Ukraine 1	South Ukraine 2	South Ukraine 3	South Ukraine 4
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	605SUP	646SUP	701SUP	702SUP	315SUP	316SUP	628SUP	692SUP	491SUP	492SUP	653SUP	691SUP
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	Russia	Russia	Russia	Russia	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine
Start of operations					1980	1982	1987		1983	1985		
Status	Under Const	Operating	Under Const	Under Const	Operating	Operating	Operating	Under Const	Operating	Operating	Operating	Under Const
Size (MWe) (Net)	950	950	950	950	361	384	950	950	950	950	950	950
Vendor	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM
A/E	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	2	2	1	1	1	1	1	1
Cooling												
Date EOL metal available	2053	2053	2053	2053	2030	2032	2037	2053	2033	2035	2053	2053
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	46	46	80	80	80	80	80	80
Surf. contam.-cleanable	15	15	15	15	9	9	15	15	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	3	3	5	5	5	5	5	5
Copper Non-radioactive	4900	4900	4900	4900	2840	2840	4900	4900	4900	4900	4900	4900
Surf. contam.-cleanable	80	80	80	80	46	46	80	80	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	12	12	20	20	20	20	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	12030	12030	19248	19248	19248	19248	19248	19248
Surf. contam.-cleanable	7156	7156	7156	7156	4669	4669	7156	7156	7156	7156	7156	7156
Surf. contam.-non-clnbl	69	69	69	69	46	46	69	69	69	69	69	69
Activated	581	581	581	581	363	363	581	581	581	581	581	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	2600	2600	2600	2600	1599	1599	2600	2600	2600	2600	2600	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	406	406	406	406	254	254	406	406	406	406	406	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

FSU

	Tatar 1	Tatar 2	Tatar 3	Tatar 4	Voronezh 1 [HO]	Voronezh 2 [HO]	Zapo-rozhye 1	Zapo-rozhye 2	Zapo-rozhye 3	Zapo-rozhye 4	Zapo-rozhye 5	Zapo-rozhye 6
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	677SUP	879SUP	880SUP	881SUP	657SUP	656SUP	606SUP	607SUP	647SUP	648SUP	697SUP	700SUP
Plant type	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER	WER
Location	Russia	Russia	Russia	Russia	Russia	Russia	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine
Start of operations							1985	1985	1987	1988	1990	
Status	Under Const	Under Const	Planned	Planned	Under Const	Under Const	Operating	Operating	Operating	Operating	Operating	Under Const
Size (MWe) (Net)	950	950	950	950	150	150	950	950	950	950	950	950
Vendor	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM	MTM
A/E	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP	AEP
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling												
Date EOL metal available	2053	2053	Unknown	Unknown	2053	2053	2035	2035	2037	2038	2040	2053
Quantity of metal (tonnes):												
Aluminum Non-radioactive	80	80	80	80	46	46	80	80	80	80	80	80
Surf. contam.-cleanable	15	15	15	15	9	9	15	15	15	15	15	15
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	3	3	5	5	5	5	5	5
Copper Non-radioactive	4900	4900	4900	4900	2840	2840	4900	4900	4900	4900	4900	4900
Surf. contam.-cleanable	80	80	80	80	46	46	80	80	80	80	80	80
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	20	20	20	20	12	12	20	20	20	20	20	20
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	19248	19248	19248	19248	12030	12030	19248	19248	19248	19248	19248	19248
Surf. contam.-cleanable	7156	7156	7156	7156	4669	4669	7156	7156	7156	7156	7156	7156
Surf. contam.-non-clnbl	69	69	69	69	46	46	69	69	69	69	69	69
Activated	581	581	581	581	363	363	581	581	581	581	581	581
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	2600	2600	2600	2600	1599	1599	2600	2600	2600	2600	2600	2600
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	406	406	406	406	254	254	406	406	406	406	406	406
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Japan

	Fukushima Daiichi 1	Fukushima Daiichi 2	Fukushima Daiichi 3	Fukushima Daiichi 4	Fukushima Daiichi 5	Fukushima Daiichi 6	Fukushima Daini 1	Fukushima Daini 2	Fukushima Daini 3	Fukushima Daini 4	Genkai 1	Hamaoka 1	Hamaoka 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	147JB	223JB	284JB	369JB	321JB	372JB	561JB	621JB	649JB	650JB	236JP	255JB	370JB
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR
Location	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan
Start of operations	1971	1974	1976	1978	1978	1979	1982	1984	1985	1987	1975	1976	1978
Status	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	439	760	760	760	760	1067	1067	1067	1067	1067	529	515	815
Vendor	GE	GE/Toshiba	Toshiba	Hitachi	Toshiba	GE/Toshiba	Toshiba	Hitachi	Toshiba	Hitachi	MHI	Toshiba	Toshiba
A/E	GE	Ebasco	Toshiba	Hitachi	Toshiba	Ebasco	Toshiba	Hitachi	Toshiba	Hitachi	Mapi	Toshiba	Tshba/Htchi
Pre or Post TMI	Pre	Pre	Pre	Pre	Pre	Pre	Post	Post	Post	Post	Pre	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea	Sea		
Date EOL metal available	2021	2024	2026	2028	2028	2029	2032	2034	2035	2037	2025	2026	2028
Quantity of metal (tonnes):													
Aluminum Non-radioactive	46	67	67	67	67	84	84	84	84	84	52	51	70
Surf. contam.-cleanable	9	12	12	12	12	16	16	16	16	16	10	10	13
Surf. contam.-non-cinbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	4	4	4	4	5	5	5	5	5	3	3	4
Copper Non-radioactive	2830	4081	4081	4081	4081	5116	5116	5116	5116	5116	3205	3148	4275
Surf. contam.-cleanable	46	67	67	67	67	84	84	84	84	84	52	51	70
Surf. contam.-non-cinbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	17	17	17	17	21	21	21	21	21	13	13	17
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-cinbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	2888	4164	4164	4164	4164	5221	5221	5221	5221	5221	3270	3212	4363
Surf. contam.-cleanable	3870	5580	5580	5580	5580	6996	6996	6996	6996	6996	4382	4305	5846
Surf. contam.-non-cinbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2022	2915	2915	2915	2915	3655	3655	3655	3655	3655	2289	2249	3054
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	347	500	500	500	500	627	627	627	627	627	392	385	524
Surf. contam.-non-cinbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	387	558	558	558	558	700	700	700	700	700	438	430	585
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-cinbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0

Japan

	Hamaoka 3	Hamaoka 4	Higashidor 1	Kashiwazaki Kariwa 1	Kashiwazaki Kariwa 2	Kashiwazaki Kariwa 3	Kashiwazaki Kariwa 4	Kashiwazaki Kariwa 5	Kashiwazaki Kariwa 6	Kashiwazaki Kariwa 7	Maki	Namie-Odaka	Onagawa 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	679JB	782JB	783JB	620JB	712JB	804JB	805JB	707JB	739JB	740JB	825JB	832JB	847JB
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR
Location	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan
Start of operations	1987			1985	1990			1990					1995
Status	Operating	Under Const	Planned	Operating	Operating	Under Const	Under Const	Operating	Planned	Planned	Planned	Planned	Operating
Size (MWe) (Net)	1066	1092	1067	1067	1067	1067	1067	1067	1311	1311	796	796	796
Vendor	Toshiba			Toshiba	Toshiba	Toshiba	Hitachi	Hitachi					
A/E	Tshba/Htchi			Toshiba	Toshiba	Toshiba	Hitachi	Hitachi					
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling				Sea	Sea	Sea	Sea	Sea	Sea	Sea			Sea
Date EOL metal available	2037	2053	Unknown	2035	2040	2053	2053	2040	Unknown	Unknown	Unknown	Unknown	2045
Quantity of metal (tonnes):													
Aluminum Non-radioactive	83	85	84	84	84	84	84	84	96	96	69	69	69
Surf. contam.-cleanable	16	16	16	16	16	16	16	16	18	18	13	13	13
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	5	5	5	5	5	5	6	6	4	4	4
Copper Non-radioactive	5113	5196	5116	5116	5116	5116	5116	5116	5869	5869	4209	4209	4209
Surf. contam.-cleanable	83	85	84	84	84	84	84	84	96	96	69	69	69
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	21	21	21	21	21	21	21	21	24	24	17	17	17
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5218	5302	5221	5221	5221	5221	5221	5221	5989	5989	4294	4294	4294
Surf. contam.-cleanable	6992	7105	6996	6996	6996	6996	6996	6996	8026	8026	5755	5755	5755
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3652	3712	3655	3655	3655	3655	3655	3655	4192	4192	3006	3006	3006
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	626	636	627	627	627	627	627	627	719	719	515	515	515
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	699	710	700	700	700	700	700	700	803	803	575	575	575
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0

Japan

	Onagawa 3	Onogawa 1	Shika 1	Shimane 1	Shimane 2	Tokai 2	Toyokita 1	Toyokita 2	Tsuruga 1	Genkai 2	Genkai 3	Genkai 4	Ikata 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	848JB	271JB	844JB	283JB	713JB	368JB	882JB	883J8	118JB	580JP	719JP	720JP	436JP
Plant type	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	BWR	PWR	PWR	PWR	PWR
Location	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan
Start of operations		1984	1992	1974	1989	1978			1970	1981	1993	1995	1978
Status	Planned	Operating	Under Const	Operating	Operating	Operating	Planned	Planned	Operating	Operating	Under Const	Under Const	Operating
Size (MWe) (Net)	796	497	515	439	791	1056	1067	1067	340	529	1127	1127	538
Vendor		Toshiba	Hitachi	Hitachi	Hitachi	GE/Hitachi			GE/Hitachi	MHI	MHI	MHI	MHI
A/E		Kajima		Hitachi	Hitachi	Ebasco			Ebasco	Hitachi	Mapi	Mapi	Mapi
Pre or Post TMI	Post	Post	Post	Pre	Post	Pre	Post	Post	Pre	Post	Post	Post	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling		Sea	Sea							Sea	Sea	Sea	
Date EOL metal available	Unknown	2034	2042	2024	2039	2028	Unknown	Unknown	2020	2031	2043	2045	2028
Quantity of metal (tonnes):													
Aluminum Non-radioactive	69	50	51	46	68	83	84	84	39	52	87	87	53
Surf. contam.-cleanable	13	9	10	9	13	16	16	16	7	10	16	16	10
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	4	3	3	3	4	5	5	5	2	3	5	5	3
Copper Non-radioactive	4209	3074	3148	2830	4191	5081	5116	5116	2387	3205	5307	5307	3241
Surf. contam.-cleanable	69	50	51	46	68	83	84	84	39	52	87	87	53
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	17	13	13	12	17	21	21	21	10	13	22	22	13
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	4294	3137	3212	2888	4276	5185	5221	5221	2436	5422	8978	8978	5484
Surf. contam.-cleanable	5755	4204	4305	3870	5730	6948	6996	6996	3264	4382	7256	7256	4432
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3006	2196	2249	2022	2994	3629	3655	3655	1705	1923	3184	3184	1945
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	515	376	385	347	513	622	627	627	292	589	975	975	595
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	196	325	325	198
Activated	575	420	430	387	573	695	700	700	326	438	726	726	443
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0

Japan

	Ikata 2	Ikata 3	Mihama 2	Mihama 3	Mihama 1	N1	Ohi 1	Ohi 2	Ohi 3	Ohi 4	Oura 1	Sendai 1	Sendai 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	593JP	723JP	186JP	332JP	146JP	827JP	303JP	305JP	729JP	730JP	851JP	636JP	666JP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan
Start of operations	1982	1995	1972	1976	1970		1979	1979	1991	1992	1999	1984	1985
Status	Operating	Under Const	Operating	Operating	Operating	Planned	Operating	Operating	Under Const	Under Const	Planned	Operating	Operating
Size (MWe) (Net)	538	846	470	780	320	1300	1120	1120	1127	1127	1300	846	846
Vendor	MHI		MHI/West	MHI	West/MHI		Wstnghse	Wstnghse	MHI	MHI		Mhi	MHI
A/E	Mapi		Kepco/Mapi	Kepco/Mapi	Kepco/Glbrt		Glbrt/Kpco	Glbrt/Kpco	Kepco/Mapi	Kepco/Mapi		Mapi	Mapi
Pre or Post TMI	Post	Post	Pre	Pre	Pre	Post	Pre	Pre	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling													
Date EOL metal available	2032	2045	2022	2026	2020	Unknown	2029	2029	2041	2042	Unknown	2034	2035
Quantity of metal (tonnes):													
Aluminum Non-radioactive	53	72	48	68	37	95	86	86	87	87	95	72	72
Surf. contam.-cleanable	10	13	9	13	7	18	16	16	16	16	18	13	13
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	4	3	4	2	6	5	5	5	5	6	4	4
Copper Non-radioactive	3241	4383	2962	4152	2292	5837	5285	5285	5307	5307	5837	4383	4383
Surf. contam.-cleanable	53	72	48	68	37	95	86	86	87	87	95	72	72
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	13	18	12	17	9	24	22	22	22	22	24	18	18
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5484	7415	5011	7025	3878	9875	8941	8941	8978	8978	9875	7415	7415
Surf. contam.-cleanable	4432	5993	4050	5677	3135	7981	7226	7226	7256	7256	7981	5993	5993
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	1945	2630	1777	2491	1375	3502	3171	3171	3184	3184	3502	2630	2630
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	595	805	544	763	421	1072	971	971	975	975	1072	805	805
Surf. contam.-non-clnbl	198	268	181	254	140	357	324	324	325	325	357	268	268
Activated	443	599	405	568	313	798	723	723	726	726	798	599	599
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0

Japan

	Takahama 1	Takahama 2	Takahama 3	Takahama 4	Tomari 1	Tomari 2	Tsuruga 2	Tokai Japco	Joyo [HO]	Monju	Fugen ATR	Ohma Demo ATR
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	254JP	285JP	663JP	664JP	680JP	681JP	665JP	66JG	172JF	711JF	213JH	845JH
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	Magnox I	LMR	LMR	LWCHWR	LWCHWR
Location	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan	Japan
Start of operations	1974	1975	1985	1985	1989	1991	1987	1966	1978	1993	1979	
Status	Operating	Operating	Operating	Operating	Operating	Under Const	Operating	Operating	Operating	Under Const	Operating	Planned
Size (MWe) (Net)	780	780	830	830	550	550	1115	159	33	280	148	556
Vendor	West/MHI	MHI	MHI	MHI	MHI	MHI	MHI	GEC	Tshba, etc.	Tshba, etc.	PNC	
A/E	Kepco/Glbrt	Kepco/Mapi	Kepco/Mapi	Kepco/Mapi	Mapi	Mapi	Ob/Sh/Tak	GEC	Takenaka		PNC	
Pre or Post TMI	Pre	Pre	Post	Post	Post	Post	Post	Pre	Pre	Post	Pre	Post
No. of steam turbines	1	1	1	1	1	1	1	2		1	1	1
Cooling					Sea	Sea		Sea			Sea	
Date EOL metal available	2024	2025	2035	2035	2039	2041	2037	2016	2028	2043	2029	Unknown
Quantity of metal (tonnes):												
Aluminum Non-radioactive	68	68	71	71	54	54	86	0			24	59
Surf. contam.-cleanable	13	13	13	13	10	10	16	0			5	11
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0			0	0
Activated	4	4	4	4	3	3	5	0			2	4
Copper Non-radioactive	4152	4152	4328	4328	3289	3289	5269	1900			1492	3605
Surf. contam.-cleanable	68	68	71	71	54	54	86	50			24	59
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0			0	0
Activated	17	17	18	18	13	13	22	50			6	15
Lead Non-radioactive	20	20	20	20	20	20	20	0			20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0			0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0			0	0
Activated	0	0	0	0	0	0	0	0			0	0
Steel & Iron Non-radioactive	7025	7025	7322	7322	5565	5565	8914	3800			2436	5886
Surf. contam.-cleanable	5677	5677	5917	5917	4498	4498	7204	4950			1827	4415
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0			0	0
Activated	2491	2491	2597	2597	1974	1974	3161	1000			895	2163
St. Steel Non-radioactive	0	0	0	0	0	0	0	100			88	213
Surf. contam.-cleanable	763	763	795	795	604	604	968	0			609	1472
Surf. contam.-non-clnbl	254	254	265	265	201	201	323	0			61	147
Activated	568	568	592	592	450	450	720	0			639	1545
Zirconium Non-radioactive	0	0	0	0	0	0	0	0			0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0			0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0			0	0
Activated	0	0	0	0	0	0	0	0			25	25

India

	Kalga 1	Kalga 2	Kalga 3	Kalga 4	Kalga 5	Kalga 6	Kakrapar 1	Kakrapar 2	Madras MAPS 1	Madras MAPS 2	Narora 1	Narora 2	Rajasthan RAPS 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	724INDH	725INDH	798INDH	799INDH	800INDH	913INDH	685INDH	686INDH	250INDH	251INDH	542INDH	543INDH	115INDH
Plant type	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR
Location	India	India	India	India	India	India	India	India	India	India	India	India	India
Start of operations	1995	1996					1991	1992	1984	1986	1990	1991	1973
Status	Under Const	Under Const	Planned	Planned	Planned	Planned	Under Const	Under Const	Operating	Operating	Operating	Under Const	Operating
Size (MWe) (Net)	220	220	220	220	220	220	220	220	220	220	220	220	207
Vendor	NPC	NPC	NPC	NPC	NPC	NPC	DAE/NPC	DAE/NPC	DAE	DAE	DAE/NPC	DAE/NPC	AECL/DAE
A/E	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE	DAE	DAE/NPC	DAE/NPC	AECL/ME
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1	1
Cooling	River	River	River	River	River	River	Tower	Tower	Sea	Sea	Tower	Tower	Lake
Date EOL metal available	2045	2046	Unknown	Unknown	Unknown	Unknown	2041	2042	2034	2036	2040	2041	2023
Quantity of metal (tonnes):													
Aluminum Non-radioactive	32	32	32	32	32	32	32	32	32	32	32	32	30
Surf. contam.-cleanable	6	6	6	6	6	6	6	6	6	6	6	6	6
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2	2	2	2	2	2	2	2	2	2	2	2	2
Copper Non-radioactive	1943	1943	1943	1943	1943	1943	1943	1943	1943	1943	1943	1943	1866
Surf. contam.-cleanable	32	32	32	32	32	32	32	32	32	32	32	32	30
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	8	8	8	8	8	8	8	8	8	8	8	8	8
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	3172	3172	3172	3172	3172	3172	3172	3172	3172	3172	3172	3172	3046
Surf. contam.-cleanable	2379	2379	2379	2379	2379	2379	2379	2379	2379	2379	2379	2379	2285
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	1166	1166	1166	1166	1166	1166	1166	1166	1166	1166	1166	1166	1119
St. Steel Non-radioactive	115	115	115	115	115	115	115	115	115	115	115	115	110
Surf. contam.-cleanable	793	793	793	793	793	793	793	793	793	793	793	793	762
Surf. contam.-non-clnbl	79	79	79	79	79	79	79	79	79	79	79	79	76
Activated	833	833	833	833	833	833	833	833	833	833	833	833	800
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	25	25	25	25	25	25	25	25	25	25	25	25	25

India

	Rajasthan RAPS 2	Rajasthan RAPS 3	Rajasthan RAPS 4	Rajasthan RAPS 5	Rajasthan RAPS 6	Rajasthan RAPS 7	Rajasthan RAPS 8	Tarapur 3	Tarapur 4	Koodang-ulam 1	Koodang-ulam 2	Tarapur 1	Tarapur 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	219INDH	718INDH	717INDH	922INDH	923INDH	924INDH	925INH	920INDH	921INDH	911INDP	912INDP	113INDB	114INDB
Plant type	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PHWR	PWR	PWR	BWR	BWR
Location	India	India	India	India	India	India	India	India	India	India	India	India	India
Start of operations	1981	1995	1996									1969	1969
Status	Operating	Under Const	Under Const	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Operating	Operating
Size (MWe) (Net)	207	220	220	450	450	450	450	450	450	953	953	150	150
Vendor	AECL/DAE	NPC	NPC	NPC	NPC	NPC	NPC	NPC	NPC	AEE	AEE	GE	GE
A/E	AECL/ME	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC	DAE/NPC			Bechtel	Bechtel
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Pre	Pre
No. of steam turbines	1	1	1	1	1	1	1	1	1	2	2	1	1
Cooling	Lake	Tower	Tower	Sea	Sea	Sea	Sea	Sea	Sea			Sea	Sea
Date EOL metal available	2031	2045	2046	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	2019	2019
Quantity of metal (tonnes):													
Aluminum Non-radioactive	30	32	32	51	51	51	51	51	51	77	77	23	23
Surf. contam.-cleanable	6	6	6	10	10	10	10	10	10	15	15	4	4
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2	2	2	3	3	3	3	3	3	5	5	1	1
Copper Non-radioactive	1866	1943	1943	3131	3131	3131	3131	3131	3131	4745	4745	1383	1383
Surf. contam.-cleanable	30	32	32	51	51	51	51	51	51	77	77	23	23
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	8	8	8	13	13	13	13	13	13	19	19	6	6
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	3046	3172	3172	5112	5112	5112	5112	5112	5112	8028	8028	1412	1412
Surf. contam.-cleanable	2285	2379	2379	3834	3834	3834	3834	3834	3834	6488	6488	1891	1891
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	1119	1166	1166	1879	1879	1879	1879	1879	1879	2847	2847	988	988
St. Steel Non-radioactive	110	115	115	185	185	185	185	185	185	0	0	0	0
Surf. contam.-cleanable	762	793	793	1278	1278	1278	1278	1278	1278	872	872	169	169
Surf. contam.-non-clnbl	76	79	79	128	128	128	128	128	128	291	291	0	0
Activated	800	833	833	1342	1342	1342	1342	1342	1342	649	649	189	189
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0	0
Activated	25	25	25	25	25	25	25	25	25	0	0	0	0

Other Asia	Guangdong 1	Guangdong 2	Qinshan 1	Qinshan 2	Qinshan 3	Bushehr 1	Bushehr 2	Iraq 1	Israel 1	Wolsong 1	Wolsong 2	Kori 1
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	727CNP	728CNP	689CNP	904CNP	905CNP			787IQP	789ILP	400KH	917KH	257KP
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PHWR	PHWR	PWR
Location	China	China	China	China	China	Iran	Iran	Iraq	Israel	Korea	Korea	Korea
Start of operations								1991	1994	1982	1997	1977
Status	Under Const	Under Const	Under Const	Planned	Planned	On hold	On hold	Planned	Planned	Operating	Under Constr	Operating
Size (MWe) (Net)	900	900	288	600	600	1300	1300	600	900	629	629	556
Vendor	Framatome	Framatome				KWU	KWU			AECL		Wstnghse
A/E										AECL	AECL	Gilbert
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Pre
No. of steam turbines	1	1	1		2			1	1	1	1	1
Cooling												
Date EOL metal available	2053	2053	2053	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	2032	2047	2027
Quantity of metal (tonnes):												
Aluminum Non-radioactive	75	75	35	57	57	95	95	57	75	64	64	54
Surf. contam.-cleanable	14	14	7	11	11	18	18	11	14	12	12	10
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	5	5	2	4	4	6	6	4	5	4	4	3
Copper Non-radioactive	4568	4568	2137	3486	3486	5837	5837	3486	4568	3914	3914	3313
Surf. contam.-cleanable	75	75	35	57	57	95	95	57	75	64	64	54
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	19	19	9	14	14	24	24	14	19	16	16	14
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	7728	7728	3615	5897	5897	9875	9875	5897	7728	6391	6391	5605
Surf. contam.-cleanable	6246	6246	2922	4766	4766	7981	7981	4766	6246	4793	4793	4530
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2741	2741	1282	2091	2091	3502	3502	2091	2741	2348	2348	1988
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	232	232	0
Surf. contam.-cleanable	839	839	392	640	640	1072	1072	640	839	1598	1598	609
Surf. contam.-non-clnbl	280	280	131	213	213	357	357	213	280	160	160	203
Activated	625	625	292	477	477	798	798	477	625	1677	1677	453
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	25	25	0

Other Asia

	Kori 2	Kori 3	Kori 4	Uljin 1	Uljin 2	Uljin 3	Uljin 4	Yeong-gwang 1	Yeong-gwang 2	Yeong-gwang 3	Yeong-gwang 4	Kanupp
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	490KP	602KP	601KP	643KP	637KP	918KP	919KP	600KP	599KP	731KP	735KP	140PKH
Plant type	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PHWR
Location	Korea	Korea	Korea	Korea	Korea	Korea	Korea	Korea	Korea	Korea	Korea	Pakistan
Start of operations	1983	1985	1985	1988	1989	1998	1999	1986	1986	1995	1996	1972
Status	Operating	Operating	Operating	Operating	Operating	Under Constr	Under Constr	Operating	Operating	Under Const	Under Const	Operating
Size (MWe) (Net)	605	895	895	943	943	943	943	900	900	900	900	125
Vendor	Wstnghse	Wstnghse	Wstnghse	Framatome	Framatome	ABB-CE	ABB-CE	Westinghouse	Westinghouse	ABB-CE	ABB-CE	CanGE
A/E	Gilbert	Bechtel	Bechtel	Framatome	Framatome	Sarg & Lun	Sarg & Lun	Bechtel	Bechtel	Sarg & Lun	Sarg & Lun	CanGe
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Pre
No. of steam turbines	1	1	1	1	1			1	1	1	1	1
Cooling												
Date EOL metal available	2033	2035	2035	2038	2039	2048	2049	2036	2036	2045	2046	2022
Quantity of metal (tonnes):												
Aluminum Non-radioactive	57	74	74	77	77	77	77	75	75	75	75	22
Surf. contam.-cleanable	11	14	14	14	14	14	14	14	14	14	14	4
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	4	5	5	5	5	5	5	5	5	5	5	1
Copper Non-radioactive	3505	4551	4551	4712	4712	4712	4712	4568	4568	4568	4568	1333
Surf. contam.-cleanable	57	74	74	77	77	77	77	75	75	75	75	22
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	14	19	19	19	19	19	19	19	19	19	19	5
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	5930	7699	7699	7972	7972	7972	7972	7728	7728	7728	7728	2176
Surf. contam.-cleanable	4793	6222	6222	6443	6443	6443	6443	6246	6246	6246	6246	1632
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	2103	2730	2730	2827	2827	2827	2827	2741	2741	2741	2741	800
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	79
Surf. contam.-cleanable	644	836	836	865	865	865	865	839	839	839	839	544
Surf. contam.-non-clnbl	215	279	279	288	288	288	288	280	280	280	280	54
Activated	479	622	622	644	644	644	644	625	625	625	625	571
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	25

Other Asia	Chasnupp	Chashma	Chin-shan 1	Chin-shan 2	Kuosheng 1	Kuosheng 2	Maanshan 1	Maanshan 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier		772PKP	279ROCB	280ROCB	458ROCB	460ROCB	531ROCP	594ROCP
Plant type	PWR	PWR	BWR	BWR	BWR	BWR	PWR	PWR
Location	Pakistan	Pakistan	Taiwan	Taiwan	Taiwan	Taiwan	Taiwan	Taiwan
Start of operations		1995	1978	1979	1981	1983	1986	1985
Status	Under Const	Planned	Operating	Operating	Operating	Operating	Operating	Operating
Size (MWe) (Net)	300	864	604	604	948	948	890	890
Vendor	CNCC		GE	GE	GE	GE	Westinghouse	Westinghouse
A/E	CNCC		Ebasco	Ebasco	Bechtel	Bechtel	Bechtel	Bechtel
Pre or Post TMI	Post	Post	Pre	Pre	Post	Post	Post	Post
No. of steam turbines		1	1	1	1	1	1	1
Cooling			Sea	Sea	Sea	Sea	Sea	Sea
Date EOL metal available	2053	Unknown	2028	2029	2031	2033	2036	2035
Quantity of metal (tonnes):								
Aluminum Non-radioactive	36	73	57	57	77	77	74	74
Surf. contam.-cleanable	7	14	11	11	14	14	14	14
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0
Activated	2	5	4	4	5	5	5	5
Copper Non-radioactive	2196	4445	3501	3501	4729	4729	4534	4534
Surf. contam.-cleanable	36	73	57	57	77	77	74	74
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0
Activated	9	18	14	14	19	19	19	19
Lead Non-radioactive	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	3715	7520	3573	3573	4825	4825	7670	7670
Surf. contam.-cleanable	3003	6078	4787	4787	6466	6466	6199	6199
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0
Activated	1318	2667	2501	2501	3378	3378	2720	2720
St. Steel Non-radioactive	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	403	816	429	429	579	579	833	833
Surf. contam.-non-clnbl	134	272	0	0	0	0	278	278
Activated	300	608	479	479	647	647	620	620
Zirconium Non-radioactive	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0

Rest of World	Atucha 1	Atucha 2	Embalse	Angra 1	Angra 2	Angra 3	Furnas 4	Furnas 5	Juragua 1	Juragua 2	Juragua 3	Juragua 4
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	176RAH	638RAH	282RAH	309BRP	488BRP	489BRP	779BRP	780BRP	694CUP	690CUP	796CUP	797CUP
Plant type	PHWR	PHWR	PHWR	PWR	PWR	PWR	PWR	PWR	WER	WER	WER	WER
Location	Argentina	Argentina	Argentina	Brazil	Brazil	Brazil	Brazil	Brazil	Cuba	Cuba	Cuba	Cuba
Start of operations	1974	1994	1984	1985	1992	1995						
Status	Operating	Under Const	Operating	Operating	Under Const	Under Const	Planned	Planned	Under Const	Under Const	Planned	Planned
Size (MWe) (Net)	335	692	600	626	1245	1245	1245	1245	408	408	408	408
Vendor	Siemens	KWU	AECL	Wstnghse	KWU	KWU	KWU	KWU				
A/E	Siemens	ENACE	AECL/Italimp	G&H/Prmn	Nuclen	Nuclen						
Pre or Post TMI	Pre	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling												
Date EOL metal available	2024	2053	2034	2035	2042	2045	Unknown	Unknown	2053	2053	UnKnown	Unknown
Quantity of metal (tonnes):												
Aluminum Non-radioactive	42	68	62	59	93	93	93	93	46	46	46	46
Surf. contam.-cleanable	8	13	12	11	17	17	17	17	9	9	9	9
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	4	4	4	6	6	6	6	3	3	3	3
Copper Non-radioactive	2572	4171	3793	3586	5671	5671	5671	5671	2840	2840	2840	2840
Surf. contam.-cleanable	42	68	62	59	93	93	93	93	46	46	46	46
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	10	17	15	15	23	23	23	23	12	12	12	12
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	4199	6810	6193	6066	9594	9594	9594	9594	12030	12030	12030	12030
Surf. contam.-cleanable	3149	5108	4644	4903	7754	7754	7754	7754	4669	4669	4669	4669
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	46	46	46	46
Activated	1543	2503	2276	2151	3402	3402	3402	3402	363	363	363	363
St. Steel Non-radioactive	152	247	224	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1050	1703	1548	659	1042	1042	1042	1042	1599	1599	1599	1599
Surf. contam.-non-clnbl	105	170	155	220	347	347	347	347	0	0	0	0
Activated	1102	1788	1626	490	775	775	775	775	254	254	254	254
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	25	25	25	0	0	0	0	0	0	0	0	0

Rest of World	Oriente 1	Oriente 2	Plunardel RIO 2	Plunardel RIO 1	El Dabaa 1	El Dabaa 2	El Dabaa 3	El Dabaa 4	Libya 1	Libya 2	Koeberg 1	Koegerg 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor	Reactor
Identifier	849CUP	850CUP	857CUP	856CUP	774EGP	775EGP	776EGP	777EGP	817LP	818LYP	576ZAP	577ZAP
Plant type	WER	WER	WER	WER	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Location	Cuba	Cuba	Cuba	Cuba	Egypt	Egypt	Egypt	Egypt	Libya	Libya	South Africa	South Africa
Start of operations									1991	1993	1984	1985
Status	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Operating	Operating
Size (MWe) (Net)	408	408	408	408	900	900	900	900	408	408	920	920
Vendor											Framatome	Framatome
A/E											Framatome	Framatome
Pre or Post TMI	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
No. of steam turbines	1	1	1	1	1	1	1	1	1	1	1	1
Cooling											Sea	Sea
Date EOL metal available	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	2034	2035
Quantity of metal (tonnes):												
Aluminum Non-radioactive	46	46	46	46	75	75	75	75	44	44	76	76
Surf. contam.-cleanable	9	9	9	9	14	14	14	14	8	8	14	14
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	3	3	3	3	5	5	5	5	3	3	5	5
Copper Non-radioactive	2840	2840	2840	2840	4568	4568	4568	4568	2695	2695	4635	4635
Surf. contam.-cleanable	46	46	46	46	75	75	75	75	44	44	76	76
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	12	12	12	12	19	19	19	19	11	11	19	19
Lead Non-radioactive	20	20	20	20	20	20	20	20	20	20	20	20
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0
Steel & Iron Non-radioactive	12030	12030	12030	12030	7728	7728	7728	7728	4560	4560	7842	7842
Surf. contam.-cleanable	4669	4669	4669	4669	6246	6246	6246	6246	3686	3686	6338	6338
Surf. contam.-non-clnbl	46	46	46	46	0	0	0	0	0	0	0	0
Activated	363	363	363	363	2741	2741	2741	2741	1617	1617	2781	2781
St. Steel Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	1599	1599	1599	1599	839	839	839	839	495	495	851	851
Surf. contam.-non-clnbl	0	0	0	0	280	280	280	280	165	165	284	284
Activated	254	254	254	254	625	625	625	625	369	369	634	634
Zirconium Non-radioactive	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-cleanable	0	0	0	0	0	0	0	0	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0	0	0	0	0	0	0	0	0
Activated	0	0	0	0	0	0	0	0	0	0	0	0

Rest of World	Kanupp	Chashma	Koeberg 1	Koegerg 2
Fuel cycle stage (FCT)	Reactor	Reactor	Reactor	Reactor
Identifier	140PKH	772PKP	576ZAP	577ZAP
Plant type	PHWR	PWR	PWR	PWR
Location	Pakistan	Pakistan	South Africa	South Africa
Start of operations	1972	1995	1984	1985
Status	Operating	Planned	Operating	Operating
Size (MWe) (Net)	125	864	920	920
Vendor	CanGE		Framatome	Framatome
A/E	CanGe		Framatome	Framatome
Pre or Post TMI	Pre	Post	Post	Post
No. of steam turbines	1	1	1	1
Cooling			Sea	Sea
Date EOL metal available	2022	Unknown	2034	2035
Quantity of metal (tonnes):				
Aluminum Non-radioactive	22	73	76	76
Surf. contam.-cleanable	4	14	14	14
Surf. contam.-non-clnbl	0	0	0	0
Activated	1	5	5	5
Copper Non-radioactive	1333	4445	4635	4635
Surf. contam.-cleanable	22	73	76	76
Surf. contam.-non-clnbl	0	0	0	0
Activated	5	18	19	19
Lead Non-radioactive	20	20	20	20
Surf. contam.-cleanable	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0
Activated	0	0	0	0
Steel & Iron Non-radioactive	2176	7520	7842	7842
Surf. contam.-cleanable	1632	6078	6338	6338
Surf. contam.-non-clnbl	0	0	0	0
Activated	800	2667	2781	2781
St. Steel Non-radioactive	79	0	0	0
Surf. contam.-cleanable	544	816	851	851
Surf. contam.-non-clnbl	54	272	284	284
Activated	571	608	634	634
Zirconium Non-radioactive	0	0	0	0
Surf. contam.-cleanable	0	0	0	0
Surf. contam.-non-clnbl	0	0	0	0
Activated	25	0	0	0

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APPENDIX B:

ANNUAL INCREMENTS IN POTENTIAL SCRAP METAL INVENTORY FROM NUCLEAR POWER PLANTS

APPENDIX B:

ANNUAL INCREMENTS IN POTENTIAL SCRAP METAL INVENTORY FROM NUCLEAR POWER PLANTS

This appendix presents tables listing annual increments in potential scrap metal inventory from nuclear power plants for various regions of the world. Each table is given in three parts — A, B, and C. Table B.1A, for example, summarizes the U.S.A. annual metal mass increments for the calendar years 2010 through 2043. Reactor metal masses are included in the appropriate year for dismantlement occurring 50 years after start-up. Table B.1B represents the same information for an additional 50-year delay, allowing for isotope decay and the transfer of metals from one activity category to another. Table B.1C shows the status after an additional 50 years decay (i.e., start-up plus 150 years).

The subsequent tables are for North America (Table B.2), Europe (Table B.3), the former Soviet Union (Table B.4), Asia (Table B.5), the rest of the world (Table B.6) and a worldwide total (Table B.7).

Following the tables are Figures B.1 through B.7, which present the data graphically. Figure B.1 gives annual iron and steel increments estimated for the U.S.A., while Figure B.2 gives total annual increments estimated for North America (U.S.A., Canada, and Mexico, excluding Cuba). Figure B.3 gives annual increments estimated for Europe, including eastern Europe (Bulgaria, Czech Republic, Finland, Hungary, Poland, Romania, Slovakia, and Slovenia). Figure B.4 gives annual increments for the former Soviet Union (including Asian portions), and Figure B.5 gives annual increments estimated for Asia (excluding Asian parts of the former Soviet Union). Figure B.6 gives annual increments estimated for the remainder of the world. Worldwide summations of the annual increment estimates are presented in Figure B.7.

Each figure has three parts — A, B, and C. Figure B.1A, for example, provides a summary of the U.S.A. annual iron and steel mass increments for the calendar years 2010 through 2043. Reactors are included in each year as appropriate for 50 years after start-up. Figure B.1B represents the same information for an additional 50-year delay, allowing for isotope decay and the transfer of metals from one activity category to another. Figure B.1C shows the status after an additional 50 years decay (i.e., at start-up plus 150 years).

TABLE B.1 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for the U.S.A.; Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	27	5	0	2	1676	27	0	7	20	0	0	0
2011	24	5	0	2	1486	24	0	6	20	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	32	6	0	2	1981	32	0	8	20	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	80	15	0	5	4900	80	0	20	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	102	19	0	6	6264	102	0	26	40	0	0	0
2019	115	22	0	7	7049	115	0	29	40	0	0	0
2020	165	31	0	10	10110	165	0	41	60	0	0	0
2021	310	58	0	19	18984	310	0	77	100	0	0	0
2022	361	68	0	23	22135	361	0	90	120	0	0	0
2023	516	97	0	32	31626	516	0	129	160	0	0	0
2024	917	172	0	57	56194	917	0	229	260	0	0	0
2025	581	109	0	36	35577	581	0	145	160	0	0	0
2026	304	57	0	19	18607	304	0	76	80	0	0	0
2027	446	84	0	28	27335	446	0	112	120	0	0	0
2028	300	56	0	19	18383	300	0	75	80	0	0	0
2029	147	28	0	9	7984	147	0	37	40	0	0	0
2030	147	28	0	9	9022	147	0	37	40	0	0	0
2031	330	62	0	21	20232	330	0	83	80	0	0	0
2032	88	16	0	5	5372	88	0	22	20	0	0	0
2033	237	44	0	15	14489	237	0	59	60	0	0	0
2034	494	93	0	31	30243	494	0	123	120	0	0	0
2035	683	128	0	43	41837	683	0	171	160	0	0	0
2036	683	128	0	43	41822	683	0	171	160	0	0	0
2037	481	90	0	30	29445	481	0	120	120	0	0	0
2038	525	98	0	33	32153	525	0	131	120	0	0	0
2039	178	33	0	11	10898	178	0	44	40	0	0	0
2040	259	48	0	16	15835	259	0	65	60	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	724	136	0	45	44367	724	0	181	160	0	0	0

TABLE B.1 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2010	1710	2291	0	1197	0	205	0	229	0	0	0	0
2011	2514	2032	0	892	0	273	91	203	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	3351	2708	0	1188	0	364	121	271	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	19248	7156	69	581	0	2600	0	406	0	0	0	100
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	10598	8566	0	3759	0	1151	384	857	0	0	0	0
2019	7193	9638	0	5035	0	863	0	964	0	0	0	0
2020	14336	13824	0	6538	0	1605	367	1382	0	0	0	0
2021	24683	25958	0	12656	0	2809	484	2596	0	0	0	0
2022	32845	30266	0	14064	0	3646	935	3027	0	0	0	0
2023	47983	43243	0	19916	0	5305	1433	4324	0	0	0	0
2024	79703	76837	0	36333	0	8920	2039	7684	0	0	0	0
2025	48607	48646	0	23318	0	5478	1122	4865	0	0	0	0
2026	31480	25443	0	11164	0	3418	1139	2544	0	0	0	0
2027	40058	37376	0	17454	0	4456	1109	3738	0	0	0	0
2028	31101	25136	0	11030	0	3376	1125	2514	0	0	0	0
2029	16938	11215	0	5017	60	1400	0	723	0	0	0	0
2030	15264	12337	0	5413	0	1657	552	1234	0	0	0	0
2031	34230	27664	0	12139	0	3716	1239	2766	0	0	0	0
2032	9089	7346	0	3223	0	987	329	735	0	0	0	0
2033	21153	19811	0	9265	0	2355	581	1981	0	0	0	0
2034	40923	41352	0	19889	0	4621	918	4135	0	0	0	0
2035	63813	57205	0	26288	0	7049	1926	5721	0	0	0	0
2036	60840	57185	0	26781	0	6777	1656	5718	0	0	0	0
2037	42956	40262	0	18835	0	4783	1177	4026	0	0	0	0
2038	47481	43964	0	20469	0	5275	1338	4396	0	0	0	0
2039	18437	14901	0	6539	0	2002	667	1490	0	0	0	0
2040	23381	21652	0	10081	0	2598	659	2165	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	71336	60665	0	27254	0	7809	2377	6067	0	0	0	0

TABLE B.1 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	31	3	0	1	1689	14	0	7	20	0	0	0
2061	27	2	0	1	1498	12	0	6	20	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	36	3	0	1	1997	16	0	8	20	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	90	8	0	3	4940	40	0	20	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	115	10	0	3	6315	51	0	26	40	0	0	0
2069	129	11	0	4	7106	58	0	29	40	0	0	0
2070	186	15	0	5	10193	83	0	41	60	0	0	0
2071	349	29	0	10	19139	155	0	77	100	0	0	0
2072	407	34	0	11	22315	181	0	90	120	0	0	0
2073	581	48	0	16	31884	258	0	129	160	0	0	0
2074	1032	86	0	29	56653	459	0	229	260	0	0	0
2075	653	54	0	18	35867	290	0	145	160	0	0	0
2076	342	28	0	9	18759	152	0	76	80	0	0	0
2077	502	42	0	14	27558	223	0	112	120	0	0	0
2078	338	28	0	9	18533	150	0	75	80	0	0	0
2079	165	14	0	5	8058	73	0	37	40	0	0	0
2080	166	14	0	5	9096	74	0	37	40	0	0	0
2081	372	31	0	10	20397	165	0	83	80	0	0	0
2082	99	8	0	3	5416	44	0	22	20	0	0	0
2083	266	22	0	7	14607	118	0	59	60	0	0	0
2084	555	46	0	15	30490	247	0	123	120	0	0	0
2085	768	64	0	21	42178	342	0	171	160	0	0	0
2086	768	64	0	21	42163	341	0	171	160	0	0	0
2087	541	45	0	15	29686	240	0	120	120	0	0	0
2088	591	49	0	16	32415	262	0	131	120	0	0	0
2089	200	17	0	6	10987	89	0	44	40	0	0	0
2090	291	24	0	8	15964	129	0	65	60	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	815	68	0	23	44729	362	0	181	160	0	0	0

TABLE B.1 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	3454	1146	0	598	103	103	0	229	0	0	0	0
2061	3976	1016	0	446	182	136	45	203	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	5299	1354	0	594	243	182	61	271	0	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	23151	3578	35	291	1300	1300	0	406	50	0	0	50
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	16760	4283	0	1879	767	575	192	857	0	0	0	0
2069	14529	4819	0	2517	432	432	0	964	0	0	0	0
2070	24517	6912	0	3269	986	802	183	1382	0	0	0	0
2071	43990	12979	0	6328	1647	1404	242	2596	0	0	0	0
2072	55010	15133	0	7032	2291	1823	468	3027	0	0	0	0
2073	79562	21622	0	9958	3369	2653	716	4324	0	0	0	0
2074	136288	38419	0	18166	5480	4460	1020	7684	0	0	0	0
2075	84588	24323	0	11659	3300	2739	561	4865	0	0	0	0
2076	49784	12721	0	5582	2278	1709	570	2544	0	0	0	0
2077	67473	18688	0	8727	2783	2228	555	3738	0	0	0	0
2078	49183	12568	0	5515	2251	1688	563	2514	0	0	0	0
2079	25054	5607	0	2509	760	700	0	723	0	0	0	0
2080	24140	6168	0	2707	1105	829	276	1234	0	0	0	0
2081	54132	13832	0	6070	2477	1858	619	2766	0	0	0	0
2082	14374	3673	0	1612	658	493	164	735	0	0	0	0
2083	35691	9906	0	4633	1468	1177	290	1981	0	0	0	0
2084	71544	20676	0	9945	2769	2310	459	4135	0	0	0	0
2085	105560	28603	0	13144	4488	3524	963	5721	0	0	0	0
2086	102823	28592	0	13390	4217	3389	828	5718	0	0	0	0
2087	72505	20131	0	9417	2980	2391	589	4026	0	0	0	0
2088	79698	21982	0	10234	3306	2637	669	4396	0	0	0	0
2089	29157	7451	0	3269	1334	1001	334	1490	0	0	0	0
2090	39247	10826	0	5041	1628	1299	329	2165	0	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	115296	30333	0	13627	5093	3905	1188	6067	0	0	0	0

TABLE B.1 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Clean-able	Non-clean-able	Activated	Non-active	Clean-able	Non-clean-able	Activated	Non-active	Clean-able	Non-clean-able	Activated
2110	32	1	0	0	1696	7	0	2	20	0	0	0
2111	29	1	0	0	1504	6	0	2	20	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	38	2	0	1	2005	8	0	2	20	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	95	4	0	1	4960	20	0	5	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	121	5	0	2	6341	26	0	6	40	0	0	0
2119	137	5	0	2	7135	29	0	7	40	0	0	0
2120	196	8	0	3	10234	41	0	10	60	0	0	0
2121	368	15	0	5	19217	77	0	19	100	0	0	0
2122	429	17	0	6	22406	90	0	23	120	0	0	0
2123	613	24	0	8	32013	129	0	32	160	0	0	0
2124	1089	43	0	14	56883	229	0	57	260	0	0	0
2125	690	27	0	9	36012	145	0	36	160	0	0	0
2126	361	14	0	5	18835	76	0	19	80	0	0	0
2127	530	21	0	7	27669	112	0	28	120	0	0	0
2128	356	14	0	5	18608	75	0	19	80	0	0	0
2129	174	7	0	2	8094	37	0	9	40	0	0	0
2130	175	7	0	2	9133	37	0	9	40	0	0	0
2131	392	15	0	5	20480	83	0	21	80	0	0	0
2132	104	4	0	1	5438	22	0	5	20	0	0	0
2133	281	11	0	4	14666	59	0	15	60	0	0	0
2134	586	23	0	8	30613	123	0	31	120	0	0	0
2135	811	32	0	11	42349	171	0	43	160	0	0	0
2136	811	32	0	11	42334	171	0	43	160	0	0	0
2137	571	23	0	8	29806	120	0	30	120	0	0	0
2138	623	25	0	8	32546	131	0	33	120	0	0	0
2139	211	8	0	3	11031	44	0	11	40	0	0	0
2140	307	12	0	4	16029	65	0	16	60	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	860	34	0	11	44910	181	0	45	160	0	0	0

TABLE B.1 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	4147	573	0	479	154	51	0	0	0	0	0	0
2111	4573	508	0	357	273	68	23	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	6095	677	0	475	364	91	30	0	0	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	25015	1789	17	232	1950	650	0	0	0	0	0	0
2117	0	0	0	0	0	0	0	0	75	0	0	25
2118	19278	2141	0	1503	1151	288	96	0	0	0	0	0
2119	17442	2410	0	2014	647	216	0	0	0	0	0	0
2120	28627	3456	0	2615	1478	401	92	0	0	0	0	0
2121	51745	6490	0	5063	2470	702	121	0	0	0	0	0
2122	63983	7566	0	5626	3436	911	234	0	0	0	0	0
2123	92365	10811	0	7966	5053	1326	358	0	0	0	0	0
2124	159131	19209	0	14533	8219	2230	510	0	0	0	0	0
2125	99082	12161	0	9327	4950	1370	280	0	0	0	0	0
2126	57261	6361	0	4466	3418	854	285	0	0	0	0	0
2127	78562	9344	0	6982	4174	1114	277	0	0	0	0	0
2128	56570	6284	0	4412	3376	844	281	0	0	0	0	0
2129	28359	2804	0	2007	1110	350	0	60	0	0	0	0
2130	27765	3084	0	2165	1657	414	138	0	0	0	0	0
2131	62262	6916	0	4856	3716	929	310	0	0	0	0	0
2132	16532	1836	0	1289	987	247	82	0	0	0	0	0
2133	41571	4953	0	3706	2202	589	145	0	0	0	0	0
2134	83871	10338	0	7956	4154	1155	229	0	0	0	0	0
2135	122490	14301	0	10515	6731	1762	482	0	0	0	0	0
2136	119798	14296	0	10712	6325	1694	414	0	0	0	0	0
2137	84454	10065	0	7534	4470	1196	294	0	0	0	0	0
2138	92736	10991	0	8188	4960	1319	334	0	0	0	0	0
2139	33537	3725	0	2615	2002	500	167	0	0	0	0	0
2140	45669	5413	0	4033	2442	649	165	0	0	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	133188	15166	0	10902	7639	1952	594	0	0	0	0	0

TABLE B.2 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for North America (U.S.A., Canada, and Mexico, excludes Cuba); Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2010	27	5	0	2	1676	27	0	7	20	0	0	0
2011	24	5	0	2	1486	24	0	6	20	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	32	6	0	2	1981	32	0	8	20	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	80	15	0	5	4900	80	0	20	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	133	25	0	8	8124	133	0	33	60	0	0	0
2019	115	22	0	7	7049	115	0	29	40	0	0	0
2020	165	31	0	10	10110	165	0	41	60	0	0	0
2021	422	79	0	26	25836	422	0	105	140	0	0	0
2022	452	85	0	28	27676	452	0	113	160	0	0	0
2023	572	107	0	36	35052	572	0	143	180	0	0	0
2024	917	172	0	57	56194	917	0	229	260	0	0	0
2025	581	109	0	36	35577	581	0	145	160	0	0	0
2026	304	57	0	19	18607	304	0	76	80	0	0	0
2027	592	111	0	37	36285	592	0	148	160	0	0	0
2028	373	70	0	23	22858	373	0	93	100	0	0	0
2029	220	41	0	14	12460	220	0	55	60	0	0	0
2030	147	28	0	9	9022	147	0	37	40	0	0	0
2031	330	62	0	21	20232	330	0	83	80	0	0	0
2032	88	16	0	5	5372	88	0	22	20	0	0	0
2033	421	79	0	26	25810	421	0	105	120	0	0	0
2034	627	118	0	39	38408	627	0	157	160	0	0	0
2035	818	153	0	51	50089	818	0	204	200	0	0	0
2036	818	153	0	51	50074	818	0	204	200	0	0	0
2037	558	105	0	35	34181	558	0	140	140	0	0	0
2038	525	98	0	33	32153	525	0	131	120	0	0	0
2039	238	45	0	15	14590	238	0	60	60	0	0	0
2040	419	78	0	26	25635	419	0	105	100	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	945	177	0	59	57859	945	0	236	220	0	0	0

TABLE B.2 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Activated	Non-active	Clean-able	Non-clean-able	Activated	Non-active	Clean-able	Non-clean-able	Activated
2010	1710	2291	0	1197	0	205	0	229	0	0	0	0
2011	2514	2032	0	892	0	273	91	203	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	3351	2708	0	1188	0	364	121	271	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	19248	7156	69	581	0	2600	0	406	0	0	0	100
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	13635	10843	0	4874	110	1910	459	1654	0	0	0	25
2019	7193	9638	0	5035	0	863	0	964	0	0	0	0
2020	14336	13824	0	6538	0	1605	367	1382	0	0	0	0
2021	35869	34348	0	16767	405	5605	764	5532	0	0	0	50
2022	41893	37051	0	17389	328	5908	1162	5401	0	0	0	50
2023	53576	47438	0	21971	203	6703	1572	5792	0	0	0	25
2024	79703	76837	0	36333	0	8920	2039	7684	0	0	0	0
2025	48607	48646	0	23318	0	5478	1122	4865	0	0	0	0
2026	31480	25443	0	11164	0	3418	1139	2544	0	0	0	0
2027	54671	48336	0	22824	530	8110	1475	7573	0	0	0	50
2028	38408	30616	0	13715	265	5203	1308	4432	0	0	0	25
2029	24244	16695	0	7702	325	3227	183	2641	0	0	0	25
2030	15264	12337	0	5413	0	1657	552	1234	0	0	0	0
2031	34230	27664	0	12139	0	3716	1239	2766	0	0	0	0
2032	9089	7346	0	3223	0	987	329	735	0	0	0	0
2033	39636	33673	0	16057	670	6976	1043	6833	0	0	0	75
2034	54255	51351	0	24788	483	7954	1251	7635	0	0	0	50
2035	77286	67310	0	31239	488	10417	2263	9257	0	0	0	50
2036	74313	67289	0	31732	488	10146	1993	9255	0	0	0	50
2037	50688	46060	0	21676	280	6716	1371	6056	0	0	0	25
2038	47481	43964	0	20469	0	5275	1338	4396	0	0	0	0
2039	22205	19949	0	9176	0	2454	667	1995	0	0	0	0
2040	39381	33652	0	15961	580	6598	1059	6365	0	0	0	50
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	91104	77713	0	35771	580	12261	2777	10771	0	0	0	50

TABLE B.2 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	31	3	0	1	1689	14	0	7	20	0	0	0
2061	27	2	0	1	1498	12	0	6	20	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	36	3	0	1	1997	16	0	8	20	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	90	8	0	3	4940	40	0	20	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	149	12	0	4	8190	66	0	33	60	0	0	0
2069	129	11	0	4	7106	58	0	29	40	0	0	0
2070	186	15	0	5	10193	83	0	41	60	0	0	0
2071	475	40	0	13	26047	211	0	105	140	0	0	0
2072	508	42	0	14	27902	226	0	113	160	0	0	0
2073	644	54	0	18	35338	286	0	143	180	0	0	0
2074	1032	86	0	29	56653	459	0	229	260	0	0	0
2075	653	54	0	18	35867	290	0	145	160	0	0	0
2076	342	28	0	9	18759	152	0	76	80	0	0	0
2077	666	56	0	19	36582	296	0	148	160	0	0	0
2078	420	35	0	12	23045	187	0	93	100	0	0	0
2079	247	21	0	7	12570	110	0	55	60	0	0	0
2080	166	14	0	5	9096	74	0	37	40	0	0	0
2081	372	31	0	10	20397	165	0	83	80	0	0	0
2082	99	8	0	3	5416	44	0	22	20	0	0	0
2083	474	40	0	13	26020	211	0	105	120	0	0	0
2084	705	59	0	20	38722	314	0	157	160	0	0	0
2085	920	77	0	26	50497	409	0	204	200	0	0	0
2086	920	77	0	26	50483	409	0	204	200	0	0	0
2087	628	52	0	17	34460	279	0	140	140	0	0	0
2088	591	49	0	16	32415	262	0	131	120	0	0	0
2089	268	22	0	7	14709	119	0	60	60	0	0	0
2090	471	39	0	13	25844	209	0	105	100	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1063	89	0	30	58331	472	0	236	220	0	0	0

TABLE B.2 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	3454	1146	0	598	103	103	0	229	0	0	0	0
2061	3976	1016	0	446	182	136	45	203	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	5299	1354	0	594	243	182	61	271	0	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	23151	3578	35	291	1300	1300	0	406	50	0	0	50
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	21493	5421	0	2437	1295	955	230	1654	13	0	0	13
2069	14529	4819	0	2517	432	432	0	964	0	0	0	0
2070	24517	6912	0	3269	986	802	183	1382	0	0	0	0
2071	61426	17174	0	8384	3590	2803	382	5532	25	0	0	25
2072	69113	18526	0	8695	3863	2954	581	5401	25	0	0	25
2073	88280	23719	0	10985	4341	3352	786	5792	13	0	0	13
2074	136288	38419	0	18166	5480	4460	1020	7684	0	0	0	0
2075	84588	24323	0	11659	3300	2739	561	4865	0	0	0	0
2076	49784	12721	0	5582	2278	1709	570	2544	0	0	0	0
2077	90251	24168	0	11412	5322	4055	737	7573	25	0	0	25
2078	60573	15308	0	6857	3521	2602	654	4432	13	0	0	13
2079	36443	8347	0	3851	2030	1613	91	2641	13	0	0	13
2080	24140	6168	0	2707	1105	829	276	1234	0	0	0	0
2081	54132	13832	0	6070	2477	1858	619	2766	0	0	0	0
2082	14374	3673	0	1612	658	493	164	735	0	0	0	0
2083	64501	16837	0	8029	4679	3488	521	6833	38	0	0	38
2084	92324	25676	0	12394	5086	3977	625	7635	25	0	0	25
2085	126560	33655	0	15619	6828	5209	1131	9257	25	0	0	25
2086	123824	33645	0	15866	6558	5073	997	9255	25	0	0	25
2087	84556	23030	0	10838	4323	3358	685	6056	13	0	0	13
2088	79698	21982	0	10234	3306	2637	669	4396	0	0	0	0
2089	36767	9975	0	4588	1560	1227	334	1995	0	0	0	0
2090	64187	16826	0	7981	4408	3299	529	6365	25	0	0	25
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	147846	38857	0	17886	8099	6131	1388	10771	25	0	0	25

TABLE B.2 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	32	1	0	0	1696	7	0	2	20	0	0	0
2111	29	1	0	0	1504	6	0	2	20	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	38	2	0	1	2005	8	0	2	20	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	95	4	0	1	4960	20	0	5	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	158	6	0	2	8224	33	0	8	60	0	0	0
2119	137	5	0	2	7135	29	0	7	40	0	0	0
2120	196	8	0	3	10234	41	0	10	60	0	0	0
2121	501	20	0	7	26152	105	0	26	140	0	0	0
2122	537	21	0	7	28015	113	0	28	160	0	0	0
2123	680	27	0	9	35481	143	0	36	180	0	0	0
2124	1089	43	0	14	56883	229	0	57	260	0	0	0
2125	690	27	0	9	36012	145	0	36	160	0	0	0
2126	361	14	0	5	18835	76	0	19	80	0	0	0
2127	703	28	0	9	36730	148	0	37	160	0	0	0
2128	443	17	0	6	23138	93	0	23	100	0	0	0
2129	261	10	0	3	12625	55	0	14	60	0	0	0
2130	175	7	0	2	9133	37	0	9	40	0	0	0
2131	392	15	0	5	20480	83	0	21	80	0	0	0
2132	104	4	0	1	5438	22	0	5	20	0	0	0
2133	500	20	0	7	26126	105	0	26	120	0	0	0
2134	745	29	0	10	38879	157	0	39	160	0	0	0
2135	971	38	0	13	50702	204	0	51	200	0	0	0
2136	971	38	0	13	50687	204	0	51	200	0	0	0
2137	663	26	0	9	34599	140	0	35	140	0	0	0
2138	623	25	0	8	32546	131	0	33	120	0	0	0
2139	283	11	0	4	14768	60	0	15	60	0	0	0
2140	497	20	0	7	25949	105	0	26	100	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1122	44	0	15	58567	236	0	59	220	0	0	0

TABLE B.2 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	4147	573	0	479	154	51	0	0	0	0	0	0
2111	4573	508	0	357	273	68	23	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	6095	677	0	475	364	91	30	0	0	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	25015	1789	17	232	1950	650	0	0	75	0	0	25
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	24691	2711	0	1950	1887	477	115	110	19	0	0	6
2119	17442	2410	0	2014	647	216	0	0	0	0	0	0
2120	28627	3456	0	2615	1478	401	92	0	0	0	0	0
2121	71689	8587	0	6707	5182	1401	191	405	38	0	0	13
2122	80115	9263	0	6956	5630	1477	290	328	38	0	0	13
2123	102337	11860	0	8788	6410	1676	393	203	19	0	0	6
2124	159131	19209	0	14533	8219	2230	510	0	0	0	0	0
2125	99082	12161	0	9327	4950	1370	280	0	0	0	0	0
2126	57261	6361	0	4466	3418	854	285	0	0	0	0	0
2127	104618	12084	0	9130	7718	2027	369	530	38	0	0	13
2128	69598	7654	0	5486	5148	1301	327	265	19	0	0	6
2129	41387	4174	0	3081	2882	807	46	325	19	0	0	6
2130	27765	3084	0	2165	1657	414	138	0	0	0	0	0
2131	62262	6916	0	4856	3716	929	310	0	0	0	0	0
2132	16532	1836	0	1289	987	247	82	0	0	0	0	0
2133	74525	8418	0	6423	6684	1744	261	670	56	0	0	19
2134	107641	12838	0	9915	7387	1988	313	483	38	0	0	13
2135	146511	16827	0	12496	9998	2604	566	488	38	0	0	13
2136	143819	16822	0	12693	9592	2536	498	488	38	0	0	13
2137	98239	11515	0	8670	6345	1679	343	280	19	0	0	6
2138	92736	10991	0	8188	4960	1319	334	0	0	0	0	0
2139	42672	4987	0	3670	2341	613	167	0	0	0	0	0
2140	74197	8413	0	6384	6322	1649	265	580	38	0	0	13
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	170851	19428	0	14308	11859	3065	694	580	38	0	0	13

TABLE B.3 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for Europe (includes eastern Europe: Bulgaria, Czech Republic, Finland, Hungary, Poland, Romania, Slovakia, and Slovenia); Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	5	1	0	0	10298	255	0	251	20	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	23	4	0	1	5683	123	0	106	20	0	0	0
2015	33	6	0	2	20696	433	0	408	20	0	0	0
2016	80	15	0	5	5800	130	0	70	20	0	0	0
2017	147	28	0	9	7997	147	0	37	60	0	0	0
2018	112	21	0	7	5876	112	0	28	40	0	0	0
2019	142	27	0	9	7689	142	0	35	60	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	206	39	0	13	10635	206	0	52	60	0	0	0
2022	416	78	0	26	22483	416	0	104	140	0	0	0
2023	47	9	0	3	2886	47	0	12	20	0	0	0
2024	149	29	0	10	9146	149	0	38	60	0	0	0
2025	436	82	0	27	26742	436	0	110	160	0	0	0
2026	295	55	0	18	16050	295	0	74	80	0	0	0
2027	416	78	0	26	24459	416	0	104	120	0	0	0
2028	199	38	0	13	11240	199	0	50	60	0	0	0
2029	576	108	0	36	35303	576	0	145	160	0	0	0
2030	522	98	0	33	31986	522	0	131	140	0	0	0
2031	992	186	0	62	60757	992	0	248	280	0	0	0
2032	276	52	0	17	16948	276	0	70	80	0	0	0
2033	493	93	0	31	30211	493	0	124	140	0	0	0
2034	960	181	0	60	56866	960	0	241	260	0	0	0
2035	1609	303	0	101	95621	1609	0	404	420	0	0	0
2036	603	113	0	38	36948	603	0	151	140	0	0	0
2037	581	109	0	36	34581	581	0	146	140	0	0	0
2038	1045	196	0	65	61004	1045	0	261	240	0	0	0
2039	375	70	0	23	20971	375	0	94	100	0	0	0
2040	138	26	0	9	8450	138	0	35	40	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1531	291	0	97	94029	1531	0	388	500	0	0	0

TABLE B.3 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	20194	26433	0	5213	500	36	0	41	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	9902	13066	0	2988	200	169	0	189	0	0	0	0
2015	40007	51254	0	9198	800	367	122	273	0	0	0	0
2016	16570	10580	0	3100	160	900	0	165	0	0	0	0
2017	18441	11232	0	4773	60	1538	136	725	0	0	0	0
2018	14786	8331	0	3511	60	1142	0	435	0	0	0	0
2019	19180	10810	0	4373	60	1596	232	683	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	28432	15136	0	6225	120	2147	0	718	0	0	0	0
2022	53110	31634	0	13355	180	4367	346	1969	0	0	0	0
2023	4883	3946	0	1732	0	530	177	395	0	0	0	0
2024	27597	14078	92	3202	0	3622	0	982	0	0	0	0
2025	54910	38137	92	14178	0	6630	853	3388	0	0	0	0
2026	36782	22541	0	9612	120	3068	257	1458	0	0	0	0
2027	42485	33741	0	15298	60	4214	797	2976	0	0	0	0
2028	32413	16452	46	5163	60	3325	275	1034	0	0	0	0
2029	61336	49057	46	20797	0	7049	1475	4693	0	0	0	0
2030	51130	43735	0	19699	0	5603	1686	4374	0	0	0	0
2031	103816	83861	46	36168	0	11671	2981	8173	0	0	0	0
2032	33280	23959	46	9273	0	3951	625	2183	0	0	0	0
2033	58338	42095	46	16786	0	6626	1676	3997	0	0	0	0
2034	112099	79922	92	32814	120	11973	1662	6770	0	0	0	0
2035	195149	134782	184	53679	180	21143	3162	11433	0	0	0	0
2036	69736	51307	46	20828	0	7864	2088	4918	0	0	0	0
2037	71902	48367	46	19167	60	7613	1705	4226	0	0	0	0
2038	132683	84762	69	33524	180	13456	2719	6973	0	0	0	0
2039	47822	29269	0	12102	120	4219	806	2131	0	0	0	0
2040	21521	12340	46	3729	0	2629	343	1021	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	314118	137636	989	25153	1147	45373	1349	15188	0	0	0	125

TABLE B.3 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	5	0	0	0	10425	127	0	251	20	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	25	2	0	1	5745	61	0	106	20	0	0	0
2065	37	3	0	1	20912	216	0	408	20	0	0	0
2066	90	8	0	3	5865	65	0	70	20	0	0	0
2067	165	14	0	5	8070	73	0	37	60	0	0	0
2068	126	11	0	4	5932	56	0	28	40	0	0	0
2069	160	13	0	4	7760	71	0	35	60	0	0	0
2070	0	0	0	0	0	0	0	0	0	0	0	0
2071	232	19	0	6	10738	103	0	52	60	0	0	0
2072	468	39	0	13	22691	208	0	104	140	0	0	0
2073	53	4	0	1	2910	24	0	12	20	0	0	0
2074	168	14	0	5	9221	74	0	38	60	0	0	0
2075	491	41	0	14	26960	218	0	110	160	0	0	0
2076	332	28	0	9	16197	147	0	74	80	0	0	0
2077	468	39	0	13	24667	208	0	104	120	0	0	0
2078	225	19	0	6	11339	100	0	50	60	0	0	0
2079	648	54	0	18	35591	288	0	145	160	0	0	0
2080	587	49	0	16	32247	261	0	131	140	0	0	0
2081	1116	93	0	31	61252	496	0	248	280	0	0	0
2082	311	26	0	9	17086	138	0	70	80	0	0	0
2083	555	46	0	15	30458	246	0	124	140	0	0	0
2084	1081	90	0	30	57346	480	0	241	260	0	0	0
2085	1811	152	0	51	96425	804	0	404	420	0	0	0
2086	678	57	0	19	37250	301	0	151	140	0	0	0
2087	653	55	0	18	34871	290	0	146	140	0	0	0
2088	1176	98	0	33	61527	522	0	261	240	0	0	0
2089	422	35	0	12	21158	188	0	94	100	0	0	0
2090	155	13	0	4	8519	69	0	35	40	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1725	146	0	49	94795	766	0	388	500	0	0	0

TABLE B.3 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	36017	13216	0	2606	518	18	0	41	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	17929	6533	0	1494	285	85	0	189	0	0	0	0
2065	70233	25627	0	4599	1044	183	61	273	0	0	0	0
2066	23410	5290	0	1550	610	450	0	165	0	0	0	0
2067	26443	5616	0	2386	897	769	68	725	0	0	0	0
2068	20707	4166	0	1756	631	571	0	435	0	0	0	0
2069	26772	5405	0	2187	974	798	116	683	0	0	0	0
2070	0	0	0	0	0	0	0	0	0	0	0	0
2071	39113	7568	0	3112	1194	1074	0	718	0	0	0	0
2072	75604	15817	0	6678	2536	2183	173	1969	0	0	0	0
2073	7721	1973	0	866	353	265	88	395	0	0	0	0
2074	36283	7039	46	1601	1811	1811	0	982	0	0	0	0
2075	81113	19069	46	7089	3742	3315	427	3388	0	0	0	0
2076	52858	11270	0	4806	1783	1534	129	1458	0	0	0	0
2077	67004	16871	0	7649	2565	2107	398	2976	0	0	0	0
2078	43243	8226	23	2581	1860	1663	138	1034	0	0	0	0
2079	96286	24529	23	10398	4262	3525	738	4693	0	0	0	0
2080	82847	21868	0	9850	3644	2801	843	4374	0	0	0	0
2081	163854	41931	23	18084	7326	5836	1490	8173	0	0	0	0
2082	49919	11980	23	4637	2288	1976	312	2183	0	0	0	0
2083	87801	21048	23	8393	4151	3313	838	3997	0	0	0	0
2084	168512	39961	46	16407	6937	5986	831	6770	0	0	0	0
2085	289472	67391	92	26839	12333	10572	1581	11433	0	0	0	0
2086	105826	25653	23	10414	4976	3932	1044	4918	0	0	0	0
2087	105692	24183	23	9584	4719	3806	852	4226	0	0	0	0
2088	191861	42381	35	16762	8267	6728	1359	6973	0	0	0	0
2089	68508	14634	0	6051	2633	2110	403	2131	0	0	0	0
2090	29578	6170	23	1864	1486	1315	172	1021	0	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	396007	68818	495	12576	24508	22687	674	15188	63	0	0	63

TABLE B.3 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	6	0	0	0	10489	64	0	63	20	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	27	1	0	0	5775	31	0	26	20	0	0	0
2115	39	2	0	1	21021	108	0	102	20	0	0	0
2116	95	4	0	1	5898	33	0	18	20	0	0	0
2117	174	7	0	2	8107	37	0	9	60	0	0	0
2118	133	5	0	2	5960	28	0	7	40	0	0	0
2119	168	7	0	2	7795	35	0	9	60	0	0	0
2120	0	0	0	0	0	0	0	0	0	0	0	0
2121	245	10	0	3	10789	52	0	13	60	0	0	0
2122	494	20	0	7	22795	104	0	26	140	0	0	0
2123	56	2	0	1	2921	12	0	3	20	0	0	0
2124	177	7	0	2	9258	37	0	10	60	0	0	0
2125	518	21	0	7	27069	109	0	27	160	0	0	0
2126	350	14	0	5	16271	74	0	18	80	0	0	0
2127	494	19	0	6	24771	104	0	26	120	0	0	0
2128	237	9	0	3	11389	50	0	13	60	0	0	0
2129	684	27	0	9	35735	144	0	36	160	0	0	0
2130	620	24	0	8	32377	131	0	33	140	0	0	0
2131	1178	47	0	16	61500	248	0	62	280	0	0	0
2132	329	13	0	4	17155	69	0	17	80	0	0	0
2133	586	23	0	8	30581	123	0	31	140	0	0	0
2134	1141	45	0	15	57586	240	0	60	260	0	0	0
2135	1912	76	0	25	96827	402	0	101	420	0	0	0
2136	716	28	0	9	37401	151	0	38	140	0	0	0
2137	690	27	0	9	35016	145	0	36	140	0	0	0
2138	1241	49	0	16	61788	261	0	65	240	0	0	0
2139	445	18	0	6	21252	94	0	23	100	0	0	0
2140	164	7	0	2	8553	34	0	9	40	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1822	73	0	24	95177	383	0	97	500	0	0	0

TABLE B.3 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	43146	6608	0	2085	527	9	0	500	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	21494	3267	0	1195	327	42	0	200	0	0	0	0
2115	83966	12814	0	3679	1167	92	31	800	0	0	0	0
2116	26365	2645	0	1240	835	225	0	160	0	0	0	0
2117	29728	2808	0	1909	1315	384	34	60	0	0	0	0
2118	23141	2083	0	1404	916	285	0	60	0	0	0	0
2119	29912	2703	0	1749	1431	399	58	60	0	0	0	0
2120	0	0	0	0	0	0	0	0	0	0	0	0
2121	43519	3784	0	2490	1730	537	0	120	0	0	0	0
2122	84848	7908	0	5342	3715	1092	87	180	0	0	0	0
2123	8881	987	0	693	530	133	44	0	0	0	0	0
2124	40146	3519	23	1281	2717	906	0	0	0	0	0	0
2125	92088	9534	23	5671	5613	1658	213	0	0	0	0	0
2126	59454	5635	0	3845	2614	767	64	120	0	0	0	0
2127	76969	8435	0	6119	3818	1054	199	60	0	0	0	0
2128	47884	4113	12	2065	2761	831	69	60	0	0	0	0
2129	110642	12264	12	8319	6394	1762	369	0	0	0	0	0
2130	95751	10934	0	7880	5467	1401	422	0	0	0	0	0
2131	188448	20965	12	14467	10989	2918	745	0	0	0	0	0
2132	56847	5990	12	3709	3432	988	156	0	0	0	0	0
2133	100015	10524	12	6714	6227	1657	419	0	0	0	0	0
2134	191797	19980	23	13125	10346	2993	416	120	0	0	0	0
2135	328581	33695	46	21471	18409	5286	791	180	0	0	0	0
2136	120747	12827	12	8331	7464	1966	522	0	0	0	0	0
2137	119712	12092	12	7667	7048	1903	426	60	0	0	0	0
2138	216421	21191	17	13409	12311	3364	680	180	0	0	0	0
2139	77035	7317	0	4841	3889	1055	202	120	0	0	0	0
2140	33048	3085	12	1492	2230	657	86	0	0	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	433178	34409	247	10061	36189	11343	337	1147	94	0	0	31

TABLE B.4 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for the Former Soviet Union (includes Asian part of the former Soviet Union); Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	126	24	0	8	7740	126	0	32	20	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0
2019	80	15	0	5	4900	80	0	20	0	0	0	0
2020	46	9	0	3	2840	46	0	12	20	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	46	9	0	3	2840	46	0	12	20	0	0	0
2023	138	27	0	9	8520	138	0	36	60	0	0	0
2024	80	15	0	5	4900	80	0	20	0	0	0	0
2025	0	0	0	0	0	0	0	0	0	0	0	0
2026	126	24	0	8	7740	126	0	32	20	0	0	0
2027	80	15	0	5	4900	80	0	20	0	0	0	0
2028	80	15	0	5	4900	80	0	20	0	0	0	0
2029	160	30	0	10	9800	160	0	40	0	0	0	0
2030	172	33	0	11	10580	172	0	44	40	0	0	0
2031	160	30	0	10	9800	160	0	40	20	0	0	0
2032	172	33	0	11	10580	172	0	44	40	0	0	0
2033	160	30	0	10	9800	160	0	40	20	0	0	0
2034	206	39	0	13	12640	206	0	52	20	0	0	0
2035	480	90	0	30	29400	480	0	120	80	0	0	0
2036	160	30	0	10	9800	160	0	40	20	0	0	0
2037	320	60	0	20	19600	320	0	80	60	0	0	0
2038	160	30	0	10	9800	160	0	40	40	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0
2040	240	45	0	15	14700	240	0	60	40	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	2092	393	0	131	128180	2092	0	524	540	0	0	0

TABLE B.4 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	31278	11825	115	944	0	4199	0	660	0	0	0	100
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0
2019	19248	7156	69	581	0	2600	0	406	0	0	0	100
2020	12030	4669	46	363	0	1599	0	254	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	12030	4669	46	363	0	1599	0	254	0	0	0	0
2023	36090	14007	138	1089	0	4797	0	762	0	0	0	0
2024	19248	7156	69	581	0	2600	0	406	0	0	0	100
2025	0	0	0	0	0	0	0	0	0	0	0	0
2026	31278	11825	115	944	0	4199	0	660	0	0	0	100
2027	19248	7156	69	581	0	2600	0	406	0	0	0	100
2028	19248	7156	69	581	0	2600	0	406	0	0	0	100
2029	38496	14312	138	1162	0	5200	0	812	0	0	0	200
2030	43308	16494	161	1307	0	5798	0	914	0	0	0	100
2031	38496	14312	138	1162	0	5200	0	812	0	0	0	100
2032	43308	16494	161	1307	0	5798	0	914	0	0	0	100
2033	38496	14312	138	1162	0	5200	0	812	0	0	0	100
2034	50526	18981	184	1525	0	6799	0	1066	0	0	0	200
2035	115488	42936	414	3486	0	15600	0	2436	0	0	0	200
2036	38496	14312	138	1162	0	5200	0	812	0	0	0	100
2037	76992	28624	276	2324	0	10400	0	1624	0	0	0	100
2038	38496	14312	138	1162	0	5200	0	812	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0
2040	57744	21468	207	1743	0	7800	0	1218	0	0	0	100
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	505260	188238	1817	15251	0	68198	0	10658	0	0	0	0

TABLE B.4 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	142	12	0	4	7803	63	0	32	20	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	0	0	0	0	0	0	0	0	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	0	0	0	0	0	0	0	0	0	0	0	0
2069	90	8	0	3	4940	40	0	20	0	0	0	0
2070	52	5	0	2	2863	23	0	12	20	0	0	0
2071	0	0	0	0	0	0	0	0	0	0	0	0
2072	52	5	0	2	2863	23	0	12	20	0	0	0
2073	156	14	0	5	8589	69	0	36	60	0	0	0
2074	90	8	0	3	4940	40	0	20	0	0	0	0
2075	0	0	0	0	0	0	0	0	0	0	0	0
2076	142	12	0	4	7803	63	0	32	20	0	0	0
2077	90	8	0	3	4940	40	0	20	0	0	0	0
2078	90	8	0	3	4940	40	0	20	0	0	0	0
2079	180	15	0	5	9880	80	0	40	0	0	0	0
2080	194	17	0	6	10666	86	0	44	40	0	0	0
2081	180	15	0	5	9880	80	0	40	20	0	0	0
2082	194	17	0	6	10666	86	0	44	40	0	0	0
2083	180	15	0	5	9880	80	0	40	20	0	0	0
2084	232	20	0	7	12743	103	0	52	20	0	0	0
2085	540	45	0	15	29640	240	0	120	80	0	0	0
2086	180	15	0	5	9880	80	0	40	20	0	0	0
2087	360	30	0	10	19760	160	0	80	60	0	0	0
2088	180	15	0	5	9880	80	0	40	40	0	0	0
2089	0	0	0	0	0	0	0	0	0	0	0	0
2090	270	23	0	8	14820	120	0	60	40	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	2354	197	0	66	129226	1046	0	524	540	0	0	0

TABLE B.4 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	37720	5913	58	472	2100	2100	0	660	50	0	0	50
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	0	0	0	0	0	0	0	0	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	0	0	0	0	0	0	0	0	0	0	0	0
2069	23151	3578	35	291	1300	1300	0	406	50	0	0	50
2070	14569	2335	23	182	800	800	0	254	0	0	0	0
2071	0	0	0	0	0	0	0	0	0	0	0	0
2072	14569	2335	23	182	800	800	0	254	0	0	0	0
2073	43707	7004	69	545	2399	2399	0	762	0	0	0	0
2074	23151	3578	35	291	1300	1300	0	406	50	0	0	50
2075	0	0	0	0	0	0	0	0	0	0	0	0
2076	37720	5913	58	472	2100	2100	0	660	50	0	0	50
2077	23151	3578	35	291	1300	1300	0	406	50	0	0	50
2078	23151	3578	35	291	1300	1300	0	406	50	0	0	50
2079	46302	7156	69	581	2600	2600	0	812	100	0	0	100
2080	52289	8247	81	654	2899	2899	0	914	50	0	0	50
2081	46302	7156	69	581	2600	2600	0	812	50	0	0	50
2082	52289	8247	81	654	2899	2899	0	914	50	0	0	50
2083	46302	7156	69	581	2600	2600	0	812	50	0	0	50
2084	60871	9491	92	763	3400	3400	0	1066	100	0	0	100
2085	138906	21468	207	1743	7800	7800	0	2436	100	0	0	100
2086	46302	7156	69	581	2600	2600	0	812	50	0	0	50
2087	92604	14312	138	1162	5200	5200	0	1624	50	0	0	50
2088	46302	7156	69	581	2600	2600	0	812	0	0	0	0
2089	0	0	0	0	0	0	0	0	0	0	0	0
2090	69453	10734	104	872	3900	3900	0	1218	50	0	0	50
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	607913	94119	909	7626	34099	34099	0	10658	0	0	0	0

TABLE B.4 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	150	6	0	2	7835	32	0	8	20	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	0	0	0	0	0	0	0	0	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	0	0	0	0	0	0	0	0	0	0	0	0
2119	95	4	0	1	4960	20	0	5	0	0	0	0
2120	55	2	0	1	2875	12	0	3	20	0	0	0
2121	0	0	0	0	0	0	0	0	0	0	0	0
2122	55	2	0	1	2875	12	0	3	20	0	0	0
2123	165	7	0	2	8624	35	0	9	60	0	0	0
2124	95	4	0	1	4960	20	0	5	0	0	0	0
2125	0	0	0	0	0	0	0	0	0	0	0	0
2126	150	6	0	2	7835	32	0	8	20	0	0	0
2127	95	4	0	1	4960	20	0	5	0	0	0	0
2128	95	4	0	1	4960	20	0	5	0	0	0	0
2129	190	8	0	3	9920	40	0	10	0	0	0	0
2130	205	8	0	3	10709	43	0	11	40	0	0	0
2131	190	8	0	3	9920	40	0	10	20	0	0	0
2132	205	8	0	3	10709	43	0	11	40	0	0	0
2133	190	8	0	3	9920	40	0	10	20	0	0	0
2134	245	10	0	3	12795	52	0	13	20	0	0	0
2135	570	23	0	8	29760	120	0	30	80	0	0	0
2136	190	8	0	3	9920	40	0	10	20	0	0	0
2137	380	15	0	5	19840	80	0	20	60	0	0	0
2138	190	8	0	3	9920	40	0	10	40	0	0	0
2139	0	0	0	0	0	0	0	0	0	0	0	0
2140	285	11	0	4	14880	60	0	15	40	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	2485	98	0	33	129749	523	0	131	540	0	0	0

TABLE B.4 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	40799	2956	29	378	3149	1050	0	0	75	0	0	25
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	0	0	0	0	0	0	0	0	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	0	0	0	0	0	0	0	0	0	0	0	0
2119	25015	1789	17	232	1950	650	0	0	75	0	0	25
2120	15784	1167	12	145	1199	400	0	0	0	0	0	0
2121	0	0	0	0	0	0	0	0	0	0	0	0
2122	15784	1167	12	145	1199	400	0	0	0	0	0	0
2123	47352	3502	35	436	3598	1199	0	0	0	0	0	0
2124	25015	1789	17	232	1950	650	0	0	75	0	0	25
2125	0	0	0	0	0	0	0	0	0	0	0	0
2126	40799	2956	29	378	3149	1050	0	0	75	0	0	25
2127	25015	1789	17	232	1950	650	0	0	75	0	0	25
2128	25015	1789	17	232	1950	650	0	0	75	0	0	25
2129	50031	3578	35	465	3900	1300	0	0	150	0	0	50
2130	56583	4124	40	523	4349	1450	0	0	75	0	0	25
2131	50031	3578	35	465	3900	1300	0	0	75	0	0	25
2132	56583	4124	40	523	4349	1450	0	0	75	0	0	25
2133	50031	3578	35	465	3900	1300	0	0	75	0	0	25
2134	65815	4745	46	610	5099	1700	0	0	150	0	0	50
2135	150092	10734	104	1394	11700	3900	0	0	150	0	0	50
2136	50031	3578	35	465	3900	1300	0	0	75	0	0	25
2137	100061	7156	69	930	7800	2600	0	0	75	0	0	25
2138	50031	3578	35	465	3900	1300	0	0	0	0	0	0
2139	0	0	0	0	0	0	0	0	0	0	0	0
2140	75046	5367	52	697	5850	1950	0	0	75	0	0	25
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	656952	47060	454	6100	51149	17050	0	0	0	0	0	0

TABLE B.5 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plant for Asia (excludes Asian parts of the former Soviet Union); Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	1900	50	0	50	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0
2019	45	8	0	3	2767	45	0	11	40	0	0	0
2020	76	14	0	5	4679	76	0	19	40	0	0	0
2021	46	9	0	3	2830	46	0	12	20	0	0	0
2022	70	13	0	4	4295	70	0	18	40	0	0	0
2023	30	6	0	2	1866	30	0	8	20	0	0	0
2024	181	34	0	11	11063	181	0	45	60	0	0	0
2025	120	23	0	8	7357	120	0	30	40	0	0	0
2026	186	35	0	12	11381	186	0	46	60	0	0	0
2027	54	10	0	3	3313	54	0	14	20	0	0	0
2028	396	74	0	25	24261	396	0	99	120	0	0	0
2029	338	63	0	21	20679	338	0	84	100	0	0	0
2030	0	0	0	0	0	0	0	0	0	0	0	0
2031	160	30	0	10	9799	160	0	40	60	0	0	0
2032	200	38	0	13	12272	200	0	50	60	0	0	0
2033	134	25	0	8	8234	134	0	34	40	0	0	0
2034	237	44	0	15	14517	237	0	59	80	0	0	0
2035	603	113	0	38	36906	603	0	151	160	0	0	0
2036	255	48	0	16	15612	255	0	64	80	0	0	0
2037	253	47	0	16	15499	253	0	63	60	0	0	0
2038	77	14	0	5	4712	77	0	19	20	0	0	0
2039	199	37	0	12	12192	199	0	50	60	0	0	0
2040	199	37	0	12	12176	199	0	50	60	0	0	0
2041	172	32	0	11	10539	172	0	43	60	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1412	265	0	88	86480	1412	0	353	460	0	0	0

TABLE B.5 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	3800	4950	0	1000	100	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0
2019	2823	3783	0	1976	0	339	0	378	0	0	0	0
2020	6314	6398	0	3080	0	713	140	640	0	0	0	0
2021	2888	3870	0	2022	0	347	0	387	0	0	0	0
2022	7188	5682	0	2577	79	1088	236	976	0	0	0	25
2023	3046	2285	0	1119	110	762	76	800	0	0	0	25
2024	14077	15127	0	7428	0	1609	254	1513	0	0	0	0
2025	10295	10060	0	4781	0	1155	254	1006	0	0	0	0
2026	14401	15562	0	7655	0	1648	254	1556	0	0	0	0
2027	5605	4530	0	1988	0	609	203	453	0	0	0	0
2028	26932	33173	0	16959	0	3169	198	3317	0	0	0	0
2029	29110	28062	0	13392	88	3605	708	3263	0	0	0	25
2030	0	0	0	0	0	0	0	0	0	0	0	0
2031	13294	13133	0	6420	110	1929	272	1884	0	0	0	25
2032	17095	16221	0	7948	232	2819	358	2820	0	0	0	25
2033	10755	11258	0	5481	0	1223	215	1126	0	0	0	0
2034	18946	19572	0	9646	115	2601	348	2552	0	0	0	25
2035	55569	50464	0	23313	0	6152	1633	5046	0	0	0	0
2036	26298	21070	0	9367	115	3304	916	2702	0	0	0	25
2037	19353	21192	0	10468	0	2220	323	2119	0	0	0	0
2038	7972	6443	0	2827	0	865	288	644	0	0	0	0
2039	17813	16671	0	7794	0	1983	490	1667	0	0	0	0
2040	13614	16371	0	8475	115	2046	79	2232	0	0	0	25
2041	17715	14133	0	6323	115	2372	606	2008	0	0	0	25
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	132915	116024	0	54011	922	18243	3840	16369	0	0	0	175

TABLE B.5 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	0	0	0	0	1925	25	0	50	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	0	0	0	0	0	0	0	0	0	0	0	0
2069	51	4	0	1	2789	23	0	11	40	0	0	0
2070	86	7	0	2	4718	38	0	19	40	0	0	0
2071	52	4	0	1	2853	23	0	12	20	0	0	0
2072	79	7	0	2	4330	35	0	18	40	0	0	0
2073	34	3	0	1	1881	15	0	8	20	0	0	0
2074	203	17	0	6	11153	90	0	45	60	0	0	0
2075	135	11	0	4	7417	60	0	30	40	0	0	0
2076	209	17	0	6	11474	93	0	46	60	0	0	0
2077	61	5	0	2	3340	27	0	14	20	0	0	0
2078	446	37	0	12	24459	198	0	99	120	0	0	0
2079	380	32	0	11	20847	169	0	84	100	0	0	0
2080	0	0	0	0	0	0	0	0	0	0	0	0
2081	180	15	0	5	9879	80	0	40	60	0	0	0
2082	225	19	0	6	12372	100	0	50	60	0	0	0
2083	151	13	0	4	8301	67	0	34	40	0	0	0
2084	267	22	0	7	14636	119	0	59	80	0	0	0
2085	678	56	0	19	37208	301	0	151	160	0	0	0
2086	287	24	0	8	15740	127	0	64	80	0	0	0
2087	285	24	0	8	15625	127	0	63	60	0	0	0
2088	87	7	0	2	4750	38	0	19	20	0	0	0
2089	224	19	0	6	12292	100	0	50	60	0	0	0
2090	224	19	0	6	12275	99	0	50	60	0	0	0
2091	194	16	0	5	10625	86	0	43	60	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1588	132	0	44	87186	706	0	353	460	0	0	0

TABLE B.5 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	6775	2475	0	500	100	0	0	0	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	0	0	0	0	0	0	0	0	0	0	0	0
2069	5703	1891	0	988	169	169	0	378	0	0	0	0
2070	11054	3199	0	1540	427	357	70	640	0	0	0	0
2071	5834	1935	0	1011	173	173	0	387	0	0	0	0
2072	11317	2841	0	1288	741	544	118	976	13	0	0	13
2073	4748	1142	0	560	529	381	38	800	13	0	0	13
2074	25354	7564	0	3714	932	804	127	1513	0	0	0	0
2075	17715	5030	0	2390	705	578	127	1006	0	0	0	0
2076	26009	7781	0	3827	951	824	127	1556	0	0	0	0
2077	8864	2265	0	994	406	304	101	453	0	0	0	0
2078	51998	16586	0	8479	1684	1585	99	3317	0	0	0	0
2079	49837	14031	0	6696	2245	1803	354	3263	13	0	0	13
2080	0	0	0	0	0	0	0	0	0	0	0	0
2081	23070	6566	0	3210	1211	965	136	1884	13	0	0	13
2082	29180	8110	0	3974	1821	1410	179	2820	13	0	0	13
2083	19125	5629	0	2740	719	611	107	1126	0	0	0	0
2084	33555	9786	0	4823	1589	1301	174	2552	13	0	0	13
2085	92457	25232	0	11657	3893	3076	817	5046	0	0	0	0
2086	41517	10535	0	4684	2225	1652	458	2702	13	0	0	13
2087	35183	10596	0	5234	1271	1110	161	2119	0	0	0	0
2088	12607	3221	0	1414	577	433	144	644	0	0	0	0
2089	30046	8336	0	3897	1236	991	245	1667	0	0	0	0
2090	26037	8186	0	4238	1178	1023	40	2232	13	0	0	13
2091	27943	7066	0	3162	1604	1186	303	2008	13	0	0	13
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	217933	58012	0	27005	11963	9121	1920	16369	88	0	0	88

TABLE B.5 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	0	0	0	0	1938	13	0	13	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	0	0	0	0	0	0	0	0	0	0	0	0
2119	54	2	0	1	2801	11	0	3	40	0	0	0
2120	91	4	0	1	4737	19	0	5	40	0	0	0
2121	55	2	0	1	2865	12	0	3	20	0	0	0
2122	83	3	0	1	4348	18	0	4	40	0	0	0
2123	36	1	0	0	1889	8	0	2	20	0	0	0
2124	214	8	0	3	11199	45	0	11	60	0	0	0
2125	143	6	0	2	7447	30	0	8	40	0	0	0
2126	221	9	0	3	11520	46	0	12	60	0	0	0
2127	64	3	0	1	3354	14	0	3	20	0	0	0
2128	470	19	0	6	24558	99	0	25	120	0	0	0
2129	401	16	0	5	20932	84	0	21	100	0	0	0
2130	0	0	0	0	0	0	0	0	0	0	0	0
2131	190	7	0	2	9919	40	0	10	60	0	0	0
2132	238	9	0	3	12422	50	0	13	60	0	0	0
2133	160	6	0	2	8335	34	0	8	40	0	0	0
2134	281	11	0	4	14695	59	0	15	80	0	0	0
2135	716	28	0	9	37358	151	0	38	160	0	0	0
2136	303	12	0	4	15803	64	0	16	80	0	0	0
2137	300	12	0	4	15688	63	0	16	60	0	0	0
2138	91	4	0	1	4770	19	0	5	20	0	0	0
2139	236	9	0	3	12342	50	0	12	60	0	0	0
2140	236	9	0	3	12325	50	0	12	60	0	0	0
2141	204	8	0	3	10668	43	0	11	60	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1677	66	0	22	87539	353	0	88	460	0	0	0

TABLE B.5 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	8113	1238	0	400	100	0	0	100	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	0	0	0	0	0	0	0	0	0	0	0	0
2119	6846	946	0	790	254	85	0	0	0	0	0	0
2120	12961	1600	0	1232	640	178	35	0	0	0	0	0
2121	7004	968	0	809	260	87	0	0	0	0	0	0
2122	12996	1421	0	1031	1072	272	59	79	19	0	0	6
2123	5431	571	0	448	739	190	19	110	19	0	0	6
2124	29879	3782	0	2971	1397	402	64	0	0	0	0	0
2125	20708	2515	0	1912	1057	289	64	0	0	0	0	0
2126	30665	3890	0	3062	1427	412	64	0	0	0	0	0
2127	10196	1133	0	795	609	152	51	0	0	0	0	0
2128	61987	8293	0	6783	2526	792	50	0	0	0	0	0
2129	58192	7015	0	5357	3323	901	177	88	19	0	0	6
2130	0	0	0	0	0	0	0	0	0	0	0	0
2131	26995	3283	0	2568	1762	482	68	110	19	0	0	6
2132	34030	4055	0	3179	2615	705	90	232	19	0	0	6
2133	22487	2815	0	2192	1078	306	54	0	0	0	0	0
2134	39413	4893	0	3859	2327	650	87	115	19	0	0	6
2135	107405	12616	0	9325	5839	1538	408	0	0	0	0	0
2136	47721	5267	0	3747	3280	826	229	115	19	0	0	6
2137	41527	5298	0	4187	1907	555	81	0	0	0	0	0
2138	14500	1611	0	1131	865	216	72	0	0	0	0	0
2139	34993	4168	0	3118	1855	496	122	0	0	0	0	0
2140	30978	4093	0	3390	1709	512	20	115	19	0	0	6
2141	32109	3533	0	2529	2348	593	151	115	19	0	0	6
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	252340	29006	0	21604	17483	4561	960	922	131	0	0	44

TABLE B.6 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for the Remainder of the World; Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0
2024	42	8	0	3	2572	42	0	10	20	0	0	0
2025	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0	0	0	0	0	0
2034	138	26	0	9	8428	138	0	34	40	0	0	0
2035	134	25	0	8	8221	134	0	34	40	0	0	0
2036	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	345	65	0	22	21193	345	0	87	100	0	0	0

TABLE B.6 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0
2024	4199	3149	0	1543	152	1050	105	1102	0	0	0	25
2025	0	0	0	0	0	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0	0	0	0	0	0
2034	14034	10982	0	5057	224	2399	439	2259	0	0	0	25
2035	13908	11241	0	4932	0	1510	503	1124	0	0	0	0
2036	0	0	0	0	0	0	0	0	0	0	0	0
2037	0	0	0	0	0	0	0	0	0	0	0	0
2038	0	0	0	0	0	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0	0	0	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	50059	29954	92	10034	247	6984	865	3846	0	0	0	25

TABLE B.6 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	0	0	0	0	0	0	0	0	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	0	0	0	0	0	0	0	0	0	0	0	0
2069	0	0	0	0	0	0	0	0	0	0	0	0
2070	0	0	0	0	0	0	0	0	0	0	0	0
2071	0	0	0	0	0	0	0	0	0	0	0	0
2072	0	0	0	0	0	0	0	0	0	0	0	0
2073	0	0	0	0	0	0	0	0	0	0	0	0
2074	47	4	0	1	2593	21	0	10	20	0	0	0
2075	0	0	0	0	0	0	0	0	0	0	0	0
2076	0	0	0	0	0	0	0	0	0	0	0	0
2077	0	0	0	0	0	0	0	0	0	0	0	0
2078	0	0	0	0	0	0	0	0	0	0	0	0
2079	0	0	0	0	0	0	0	0	0	0	0	0
2080	0	0	0	0	0	0	0	0	0	0	0	0
2081	0	0	0	0	0	0	0	0	0	0	0	0
2082	0	0	0	0	0	0	0	0	0	0	0	0
2083	0	0	0	0	0	0	0	0	0	0	0	0
2084	155	13	0	4	8497	69	0	34	40	0	0	0
2085	151	13	0	4	8288	67	0	34	40	0	0	0
2086	0	0	0	0	0	0	0	0	0	0	0	0
2087	0	0	0	0	0	0	0	0	0	0	0	0
2088	0	0	0	0	0	0	0	0	0	0	0	0
2089	0	0	0	0	0	0	0	0	0	0	0	0
2090	0	0	0	0	0	0	0	0	0	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	389	33	0	11	21366	173	0	87	100	0	0	0

TABLE B.6 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2060	0	0	0	0	0	0	0	0	0	0	0	0
2061	0	0	0	0	0	0	0	0	0	0	0	0
2062	0	0	0	0	0	0	0	0	0	0	0	0
2063	0	0	0	0	0	0	0	0	0	0	0	0
2064	0	0	0	0	0	0	0	0	0	0	0	0
2065	0	0	0	0	0	0	0	0	0	0	0	0
2066	0	0	0	0	0	0	0	0	0	0	0	0
2067	0	0	0	0	0	0	0	0	0	0	0	0
2068	0	0	0	0	0	0	0	0	0	0	0	0
2069	0	0	0	0	0	0	0	0	0	0	0	0
2070	0	0	0	0	0	0	0	0	0	0	0	0
2071	0	0	0	0	0	0	0	0	0	0	0	0
2072	0	0	0	0	0	0	0	0	0	0	0	0
2073	0	0	0	0	0	0	0	c	0	0	0	0
2074	6545	1575	0	772	730	525	52	1102	13	0	0	13
2075	0	0	0	0	0	0	0	0	0	0	0	0
2076	0	0	0	0	0	0	0	0	0	0	0	0
2077	0	0	0	0	0	0	0	0	0	0	0	0
2078	0	0	0	0	0	0	0	0	0	0	0	0
2079	0	0	0	0	0	0	0	0	0	0	0	0
2080	0	0	0	0	0	0	0	0	0	0	0	0
2081	0	0	0	0	0	0	0	0	0	0	0	0
2082	0	0	0	0	0	0	0	0	0	0	0	0
2083	0	0	0	0	0	0	0	0	0	0	0	0
2084	22054	5491	0	2528	1644	1200	219	2259	13	0	0	13
2085	21995	5620	0	2466	1007	755	252	1124	0	0	0	0
2086	0	0	0	0	0	0	0	0	0	0	0	0
2087	0	0	0	0	0	0	0	0	0	0	0	0
2088	0	0	0	0	0	0	0	0	0	0	0	0
2089	0	0	0	0	0	0	0	0	0	0	0	0
2090	0	0	0	0	0	0	0	0	0	0	0	0
2091	0	0	0	0	0	0	0	0	0	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	70098	14977	46	5017	4171	3492	432	3846	13	0	0	13

TABLE B.6 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	0	0	0	0	0	0	0	0	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	0	0	0	0	0	0	0	0	0	0	0	0
2119	0	0	0	0	0	0	0	0	0	0	0	0
2120	0	0	0	0	0	0	0	0	0	0	0	0
2121	0	0	0	0	0	0	0	0	0	0	0	0
2122	0	0	0	0	0	0	0	0	0	0	0	0
2123	0	0	0	0	0	0	0	0	0	0	0	0
2124	50	2	0	1	2603	10	0	3	20	0	0	0
2125	0	0	0	0	0	0	0	0	0	0	0	0
2126	0	0	0	0	0	0	0	0	0	0	0	0
2127	0	0	0	0	0	0	0	0	0	0	0	0
2128	0	0	0	0	0	0	0	0	0	0	0	0
2129	0	0	0	0	0	0	0	0	0	0	0	0
2130	0	0	0	0	0	0	0	0	0	0	0	0
2131	0	0	0	0	0	0	0	0	0	0	0	0
2132	0	0	0	0	0	0	0	0	0	0	0	0
2133	0	0	0	0	0	0	0	0	0	0	0	0
2134	163	6	0	2	8531	34	0	9	40	0	0	0
2135	159	6	0	2	8321	34	0	8	40	0	0	0
2136	0	0	0	0	0	0	0	0	0	0	0	0
2137	0	0	0	0	0	0	0	0	0	0	0	0
2138	0	0	0	0	0	0	0	0	0	0	0	0
2139	0	0	0	0	0	0	0	0	0	0	0	0
2140	0	0	0	0	0	0	0	0	0	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	411	16	0	5	21452	86	0	22	100	0	0	0

TABLE B.6 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	0	0	0	0	0	0	0	0	0	0	0	0
2111	0	0	0	0	0	0	0	0	0	0	0	0
2112	0	0	0	0	0	0	0	0	0	0	0	0
2113	0	0	0	0	0	0	0	0	0	0	0	0
2114	0	0	0	0	0	0	0	0	0	0	0	0
2115	0	0	0	0	0	0	0	0	0	0	0	0
2116	0	0	0	0	0	0	0	0	0	0	0	0
2117	0	0	0	0	0	0	0	0	0	0	0	0
2118	0	0	0	0	0	0	0	0	0	0	0	0
2119	0	0	0	0	0	0	0	0	0	0	0	0
2120	0	0	0	0	0	0	0	0	0	0	0	0
2121	0	0	0	0	0	0	0	0	0	0	0	0
2122	0	0	0	0	0	0	0	0	0	0	0	0
2123	0	0	0	0	0	0	0	0	0	0	0	0
2124	7487	787	0	617	1018	262	26	152	19	0	0	6
2125	0	0	0	0	0	0	0	0	0	0	0	0
2126	0	0	0	0	0	0	0	0	0	0	0	0
2127	0	0	0	0	0	0	0	0	0	0	0	0
2128	0	0	0	0	0	0	0	0	0	0	0	0
2129	0	0	0	0	0	0	0	0	0	0	0	0
2130	0	0	0	0	0	0	0	0	0	0	0	0
2131	0	0	0	0	0	0	0	0	0	0	0	0
2132	0	0	0	0	0	0	0	0	0	0	0	0
2133	0	0	0	0	0	0	0	0	0	0	0	0
2134	25305	2746	0	2023	2353	600	110	224	19	0	0	6
2135	25298	2810	0	1973	1510	377	126	0	0	0	0	0
2136	0	0	0	0	0	0	0	0	0	0	0	0
2137	0	0	0	0	0	0	0	0	0	0	0	0
2138	0	0	0	0	0	0	0	0	0	0	0	0
2139	0	0	0	0	0	0	0	0	0	0	0	0
2140	0	0	0	0	0	0	0	0	0	0	0	0
2141	0	0	0	0	0	0	0	0	0	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	78613	7488	23	4013	6133	1746	216	247	19	0	0	6

TABLE B.7 Worldwide Summations of the Annual Increments in Scrap-Metal Inventory from the Nuclear Power Plants; Part A: Start-Up Plus 50 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	27	5	0	2	1676	27	0	7	20	0	0	0
2011	24	5	0	2	1486	24	0	6	20	0	0	0
2012	5	1	0	0	10298	255	0	251	20	0	0	0
2013	32	6	0	2	1981	32	0	8	20	0	0	0
2014	149	28	0	9	13423	249	0	138	40	0	0	0
2015	33	6	0	2	20696	433	0	408	20	0	0	0
2016	160	30	0	10	12600	260	0	140	20	0	0	0
2017	147	28	0	9	7997	147	0	37	60	0	0	0
2018	245	46	0	15	14000	245	0	61	100	0	0	0
2019	382	72	0	24	22404	382	0	96	140	0	0	0
2020	287	54	0	18	17630	287	0	72	120	0	0	0
2021	674	126	0	42	39301	674	0	169	220	0	0	0
2022	984	185	0	62	57294	984	0	247	360	0	0	0
2023	788	149	0	50	48323	788	0	198	280	0	0	0
2024	1369	257	0	86	83876	1369	0	343	400	0	0	0
2025	1137	214	0	71	69676	1137	0	285	360	0	0	0
2026	910	171	0	57	53778	910	0	228	240	0	0	0
2027	1142	214	0	71	68957	1142	0	286	300	0	0	0
2028	1049	197	0	66	63258	1049	0	263	280	0	0	0
2029	1293	243	0	81	78242	1293	0	324	320	0	0	0
2030	842	159	0	53	51588	842	0	211	220	0	0	0
2031	1642	308	0	103	100588	1642	0	411	440	0	0	0
2032	736	139	0	46	45172	736	0	186	200	0	0	0
2033	1209	227	0	76	74055	1209	0	303	320	0	0	0
2034	2168	408	0	136	130860	2168	0	544	560	0	0	0
2035	3643	685	0	228	220237	3643	0	913	900	0	0	0
2036	1835	344	0	115	112434	1835	0	459	440	0	0	0
2037	1712	321	0	107	103860	1712	0	428	400	0	0	0
2038	1807	339	0	113	107669	1807	0	452	420	0	0	0
2039	812	152	0	51	47753	812	0	203	220	0	0	0
2040	995	187	0	62	60961	995	0	249	240	0	0	0
2041	172	32	0	11	10539	172	0	43	60	0	0	0
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	6325	1192	0	397	387741	6325	0	1589	1820	0	0	0

TABLE B.7 (Cont.); Part A (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2010	1710	2291	0	1197	0	205	0	229	0	0	0	0
2011	2514	2032	0	892	0	273	91	203	0	0	0	0
2012	20194	26433	0	5213	500	36	0	41	0	0	0	0
2013	3351	2708	0	1188	0	364	121	271	0	0	0	0
2014	41180	24891	115	3932	200	4368	0	849	0	0	0	100
2015	40007	51254	0	9198	800	367	122	273	0	0	0	0
2016	39618	22686	69	4681	260	3500	0	571	0	0	0	100
2017	18441	11232	0	4773	60	1538	136	725	0	0	0	0
2018	28420	19174	0	8386	170	3052	459	2089	0	0	0	25
2019	48444	31388	69	11965	60	5398	232	2431	0	0	0	100
2020	32681	24892	46	9981	0	3917	507	2276	0	0	0	0
2021	67189	53354	0	25013	525	8099	764	6637	0	0	0	50
2022	114221	79036	46	33685	587	12961	1744	8601	0	0	0	75
2023	97594	67676	138	25911	313	12792	1825	7749	0	0	0	50
2024	144824	116347	161	49086	152	17801	2398	11687	0	0	0	125
2025	113812	96843	92	42276	0	13264	2229	9258	0	0	0	0
2026	113941	75370	115	29375	120	12392	1651	6218	0	0	0	100
2027	122009	93763	69	40691	590	15532	2474	11409	0	0	0	150
2028	117000	87396	115	36417	325	14298	1782	9189	0	0	0	125
2029	153187	108126	184	43054	413	19082	2366	11409	0	0	0	250
2030	109702	72566	161	26420	0	13058	2239	6521	0	0	0	100
2031	189836	138970	184	55890	110	22517	4492	13636	0	0	0	125
2032	102772	64020	207	21752	232	13556	1312	6652	0	0	0	125
2033	147225	101339	184	39486	670	20025	2933	12767	0	0	0	175
2034	249860	180808	276	73830	943	31726	3699	20282	0	0	0	300
2035	457400	306732	598	116649	668	54822	7561	29296	0	0	0	250
2036	208843	153978	184	63089	603	26513	4998	17686	0	0	0	175
2037	218934	144243	322	53636	340	26949	3398	14025	0	0	0	125
2038	226632	149481	207	57982	180	24796	4345	12825	0	0	0	0
2039	87841	65889	0	29072	120	8656	1963	5793	0	0	0	0
2040	132260	83831	253	29908	695	19073	1481	10836	0	0	0	175
2041	17715	14133	0	6323	115	2372	606	2008	0	0	0	25
2042	0	0	0	0	0	0	0	0	0	0	0	0
2043	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1093455	549565	2898	140220	2896	151059	8829	56833	0	0	0	375

TABLE B.7 (Cont.); Part B: Start-Up Plus 100 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2060	31	3	0	1	1689	14	0	7	20	0	0	0
2061	27	2	0	1	1498	12	0	6	20	0	0	0
2062	5	0	0	0	10425	127	0	251	20	0	0	0
2063	36	3	0	1	1997	16	0	8	20	0	0	0
2064	167	14	0	5	13548	124	0	138	40	0	0	0
2065	37	3	0	1	20912	216	0	408	20	0	0	0
2066	180	15	0	5	12730	130	0	140	20	0	0	0
2067	165	14	0	5	8070	73	0	37	60	0	0	0
2068	276	23	0	8	14122	122	0	61	100	0	0	0
2069	430	36	0	12	22595	191	0	96	140	0	0	0
2070	324	27	0	9	17774	144	0	72	120	0	0	0
2071	759	63	0	21	39638	337	0	169	220	0	0	0
2072	1107	92	0	31	57786	492	0	247	360	0	0	0
2073	887	74	0	25	48717	394	0	198	280	0	0	0
2074	1540	129	0	43	84560	684	0	343	400	0	0	0
2075	1279	107	0	36	70244	568	0	285	360	0	0	0
2076	1024	86	0	29	54233	455	0	228	240	0	0	0
2077	1285	107	0	36	69528	571	0	286	300	0	0	0
2078	1180	99	0	33	63783	524	0	263	280	0	0	0
2079	1455	121	0	40	78888	647	0	324	320	0	0	0
2080	947	79	0	26	52009	421	0	211	220	0	0	0
2081	1847	154	0	51	101409	821	0	411	440	0	0	0
2082	829	70	0	23	45540	368	0	186	200	0	0	0
2083	1360	113	0	38	74659	604	0	303	320	0	0	0
2084	2440	204	0	68	131944	1084	0	544	560	0	0	0
2085	4100	342	0	114	222058	1822	0	913	900	0	0	0
2086	2065	172	0	57	113352	918	0	459	440	0	0	0
2087	1926	161	0	54	104716	856	0	428	400	0	0	0
2088	2033	169	0	56	108573	903	0	452	420	0	0	0
2089	914	76	0	25	48159	406	0	203	220	0	0	0
2090	1120	93	0	31	61458	497	0	249	240	0	0	0
2091	194	16	0	5	10625	86	0	43	60	0	0	0
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	7119	596	0	199	390903	3162	0	1589	1820	0	0	0

TABLE B.7 (Cont.); Part B (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2060	3454	1146	0	598	103	103	0	229	0	0	0	0
2061	3976	1016	0	446	182	136	45	203	0	0	0	0
2062	36017	13216	0	2606	518	18	0	41	0	0	0	0
2063	5299	1354	0	594	243	182	61	271	0	0	0	0
2064	55649	12446	58	1966	2384	2184	0	849	50	0	0	50
2065	70233	25627	0	4599	1044	183	61	273	0	0	0	0
2066	53336	11343	35	2341	2010	1750	0	571	50	0	0	50
2067	26443	5616	0	2386	897	769	68	725	0	0	0	0
2068	42200	9587	0	4193	1926	1526	230	2089	13	0	0	13
2069	70154	15694	35	5983	2875	2699	116	2431	50	0	0	50
2070	50140	12446	23	4990	2212	1958	253	2276	0	0	0	0
2071	106373	26677	0	12507	4957	4050	382	6637	25	0	0	25
2072	170604	39518	23	16842	7939	6481	872	8601	38	0	0	38
2073	144457	33838	69	12955	7622	6396	913	7749	25	0	0	25
2074	227621	58174	81	24543	10252	8901	1199	11687	63	0	0	63
2075	183417	48421	46	21138	7747	6632	1115	9258	0	0	0	0
2076	166371	37685	58	14688	7111	6166	825	6218	50	0	0	50
2077	189271	46882	35	20345	9593	7766	1237	11409	75	0	0	75
2078	178964	43698	58	18209	8365	7149	891	9189	63	0	0	63
2079	228868	54063	92	21527	11137	9541	1183	11409	125	0	0	125
2080	159276	36283	81	13210	7648	6529	1119	6521	50	0	0	50
2081	287358	69485	92	27945	13615	11258	2246	13636	63	0	0	63
2082	145761	32010	104	10876	7666	6778	656	6652	63	0	0	63
2083	217729	50669	92	19743	12149	10012	1467	12767	88	0	0	88
2084	377317	90404	138	36915	18655	15863	1850	20282	150	0	0	150
2085	669390	153366	299	58325	31860	27411	3781	29296	125	0	0	125
2086	317468	76989	92	31545	16359	13257	2499	17686	88	0	0	88
2087	318035	72122	161	26818	15513	13474	1699	14025	63	0	0	63
2088	330467	74741	104	28991	14751	12398	2173	12825	0	0	0	0
2089	135321	32945	0	14536	5430	4328	982	5793	0	0	0	0
2090	189256	41915	127	14954	10972	9537	741	10836	88	0	0	88
2091	27943	7066	0	3162	1604	1186	303	2008	13	0	0	13
2092	0	0	0	0	0	0	0	0	0	0	0	0
2093	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1439796	274782	1449	70110	82840	75529	4415	56833	188	0	0	188

TABLE B.7 (Cont.); Part C: Start-Up Plus 150 Years

Year available	Aluminum				Copper				Lead			
	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated	Non-active	Cleanable	Non-cleanable	Activated
2110	32	1	0	0	1696	7	0	2	20	0	0	0
2111	29	1	0	0	1504	6	0	2	20	0	0	0
2112	6	0	0	0	10489	64	0	63	20	0	0	0
2113	38	2	0	1	2005	8	0	2	20	0	0	0
2114	177	7	0	2	13610	62	0	34	40	0	0	0
2115	39	2	0	1	21021	108	0	102	20	0	0	0
2116	190	8	0	3	12795	65	0	35	20	0	0	0
2117	174	7	0	2	8107	37	0	9	60	0	0	0
2118	291	11	0	4	14183	61	0	15	100	0	0	0
2119	454	18	0	6	22691	96	0	24	140	0	0	0
2120	342	14	0	5	17845	72	0	18	120	0	0	0
2121	801	32	0	11	39806	169	0	42	220	0	0	0
2122	1169	46	0	15	58032	246	0	62	360	0	0	0
2123	937	37	0	12	48914	197	0	50	280	0	0	0
2124	1626	64	0	21	84902	342	0	86	400	0	0	0
2125	1351	53	0	18	70529	284	0	71	360	0	0	0
2126	1081	43	0	14	54461	228	0	57	240	0	0	0
2127	1356	54	0	18	69814	286	0	71	300	0	0	0
2128	1246	49	0	16	64045	262	0	66	280	0	0	0
2129	1536	61	0	20	79212	323	0	81	320	0	0	0
2130	1000	40	0	13	52219	210	0	53	220	0	0	0
2131	1950	77	0	26	101820	410	0	103	440	0	0	0
2132	876	35	0	12	45724	184	0	46	200	0	0	0
2133	1436	57	0	19	74961	302	0	76	320	0	0	0
2134	2576	102	0	34	132486	542	0	136	560	0	0	0
2135	4328	171	0	57	222969	911	0	228	900	0	0	0
2136	2180	86	0	29	113811	459	0	115	440	0	0	0
2137	2033	80	0	27	105144	428	0	107	400	0	0	0
2138	2146	85	0	28	109024	452	0	113	420	0	0	0
2139	965	38	0	13	48362	203	0	51	220	0	0	0
2140	1182	47	0	16	61707	249	0	62	240	0	0	0
2141	204	8	0	3	10668	43	0	11	60	0	0	0
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	7516	298	0	99	392485	1581	0	397	1820	0	0	0

TABLE B.7 (Cont.); Part C (Cont.)

Year available	Steel & Iron				Stainless steel				Zirconium			
	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated	Non-active	Clean-able	Non-clean-able	Acti-vated
2110	4147	573	0	479	154	51	0	0	0	0	0	0
2111	4573	508	0	357	273	68	23	0	0	0	0	0
2112	43146	6608	0	2085	527	9	0	500	0	0	0	0
2113	6095	677	0	475	364	91	30	0	0	0	0	0
2114	62294	6223	29	1573	3476	1092	0	200	75	0	0	25
2115	83966	12814	0	3679	1167	92	31	800	0	0	0	0
2116	59493	5672	17	1872	2885	875	0	260	75	0	0	25
2117	29728	2808	0	1909	1315	384	34	60	0	0	0	0
2118	47832	4794	0	3354	2803	763	115	170	19	0	0	6
2119	79215	7847	17	4786	4282	1349	58	60	75	0	0	25
2120	57372	6223	12	3992	3318	979	127	0	0	0	0	0
2121	122212	13338	0	10005	7173	2025	191	525	38	0	0	13
2122	193743	19759	12	13474	11616	3240	436	587	56	0	0	19
2123	164001	16919	35	10364	11276	3198	456	313	38	0	0	13
2124	261657	29087	40	19635	15302	4450	600	152	94	0	0	31
2125	211878	24211	23	16910	11620	3316	557	0	0	0	0	0
2126	188180	18842	29	11750	10607	3083	413	120	75	0	0	25
2127	216798	23441	17	16276	14095	3883	619	590	113	0	0	38
2128	204484	21849	29	14567	12385	3574	446	325	94	0	0	31
2129	260251	27031	46	17221	16499	4770	592	413	188	0	0	63
2130	180100	18142	40	10568	11472	3264	560	0	75	0	0	25
2131	327735	34743	46	22356	20367	5629	1123	110	94	0	0	31
2132	163993	16005	52	8701	11383	3389	328	232	94	0	0	31
2133	247058	25335	46	15794	17888	5006	733	670	131	0	0	44
2134	429971	45202	69	29532	27512	7931	925	943	225	0	0	75
2135	757887	76683	150	46660	47456	13706	1890	668	188	0	0	63
2136	362318	38494	46	25236	24236	6628	1249	603	131	0	0	44
2137	359539	36061	81	21454	23100	6737	849	340	94	0	0	31
2138	373687	37370	52	23193	22036	6199	1086	180	0	0	0	0
2139	154701	16472	0	11629	8084	2164	491	120	0	0	0	0
2140	213268	20958	63	11963	16111	4768	370	695	131	0	0	44
2141	32109	3533	0	2529	2348	593	151	115	19	0	0	6
2142	0	0	0	0	0	0	0	0	0	0	0	0
2143	0	0	0	0	0	0	0	0	0	0	0	0
Under const.	1591934	137391	725	56088	122812	37765	2207	2896	281	0	0	94

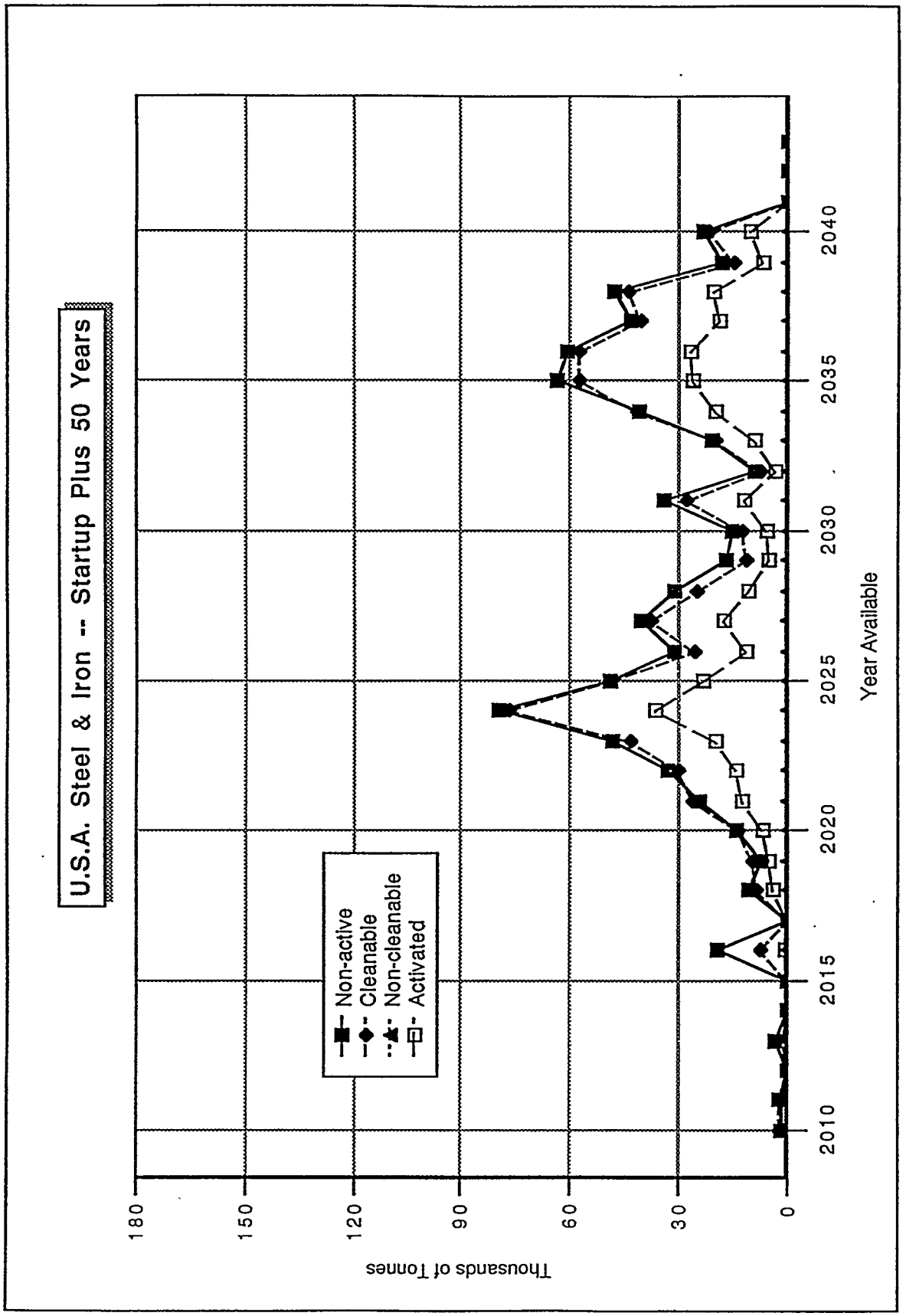


FIGURE B.1 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for the U.S.A.; Part A: Start-Up Plus 50 Years

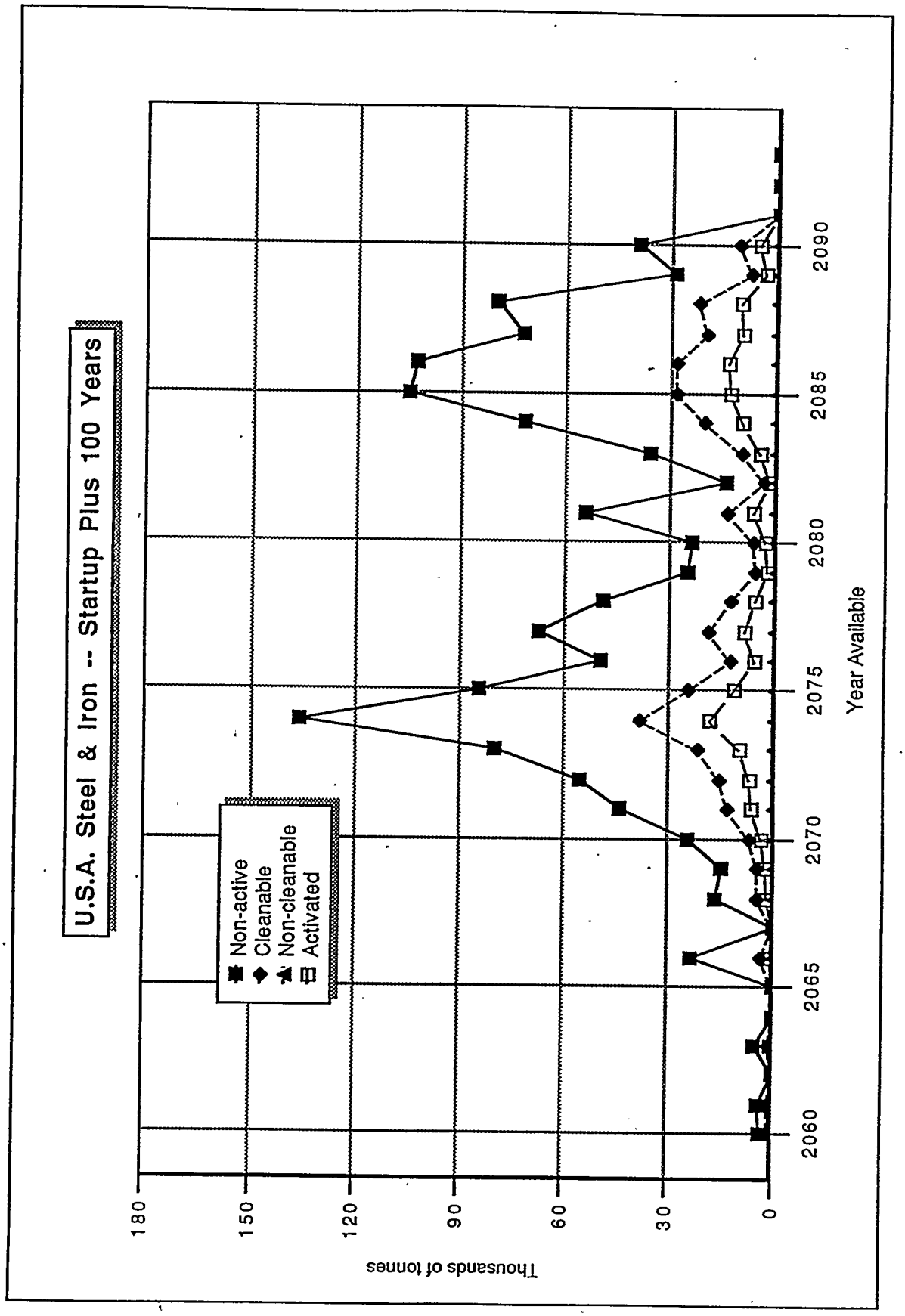


FIGURE B.1 (Cont.) Part B: Start-Up Plus 100 Years

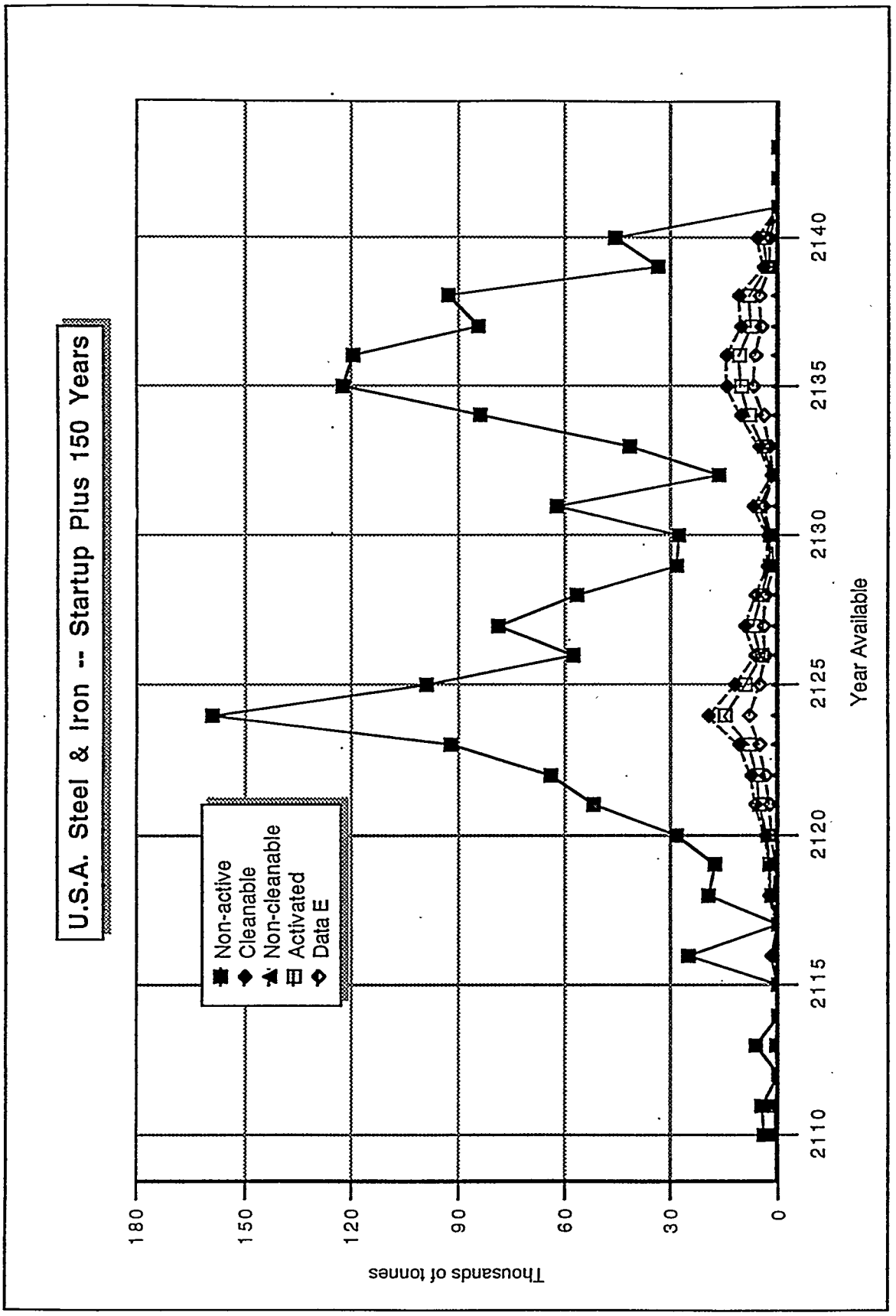


FIGURE B.1 (Cont.) Part C: Start-Up Plus 150 Years

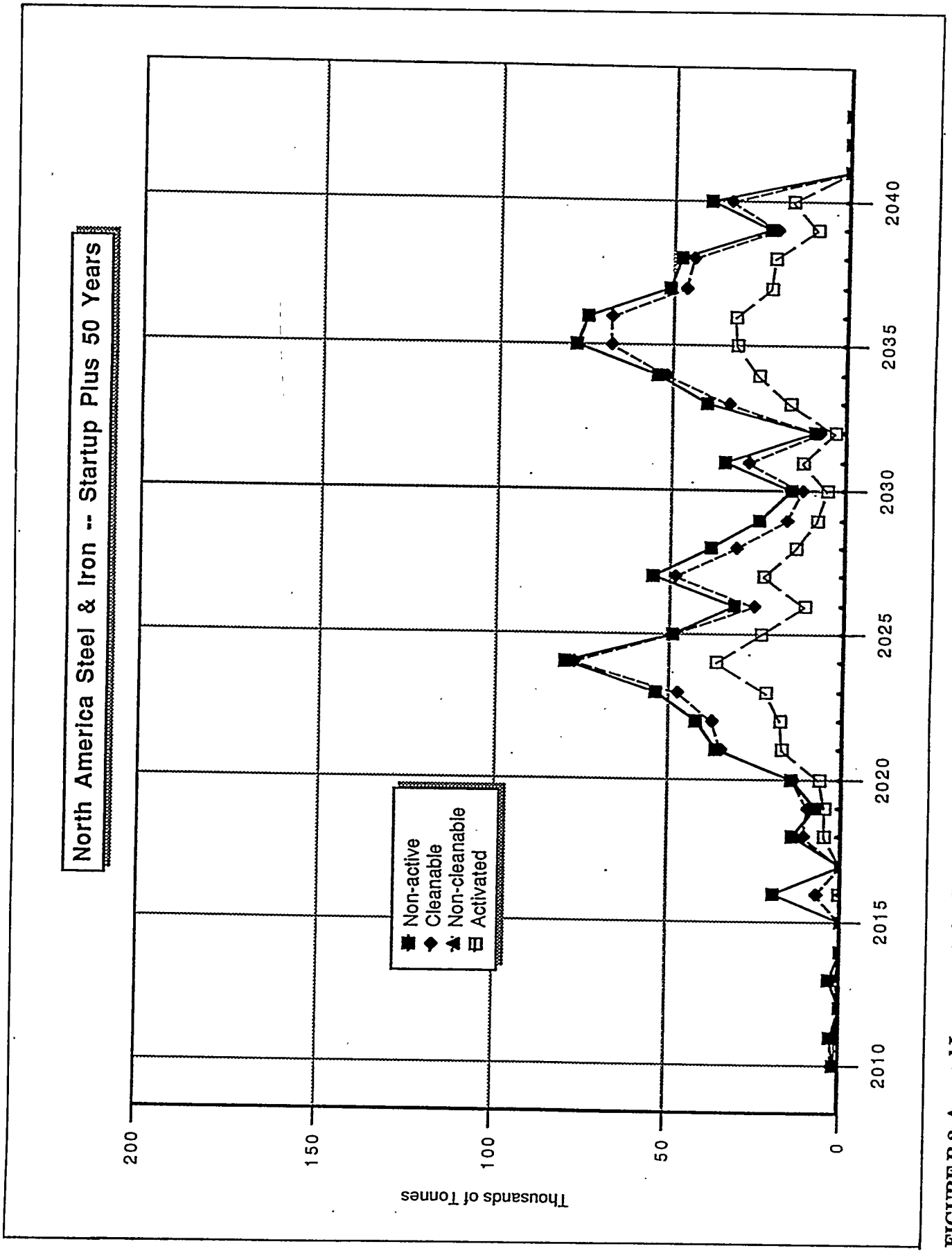


FIGURE B.2 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for North America (U.S.A., Canada, and Mexico, excludes Cuba); Part A: Start-Up Plus 50 Years

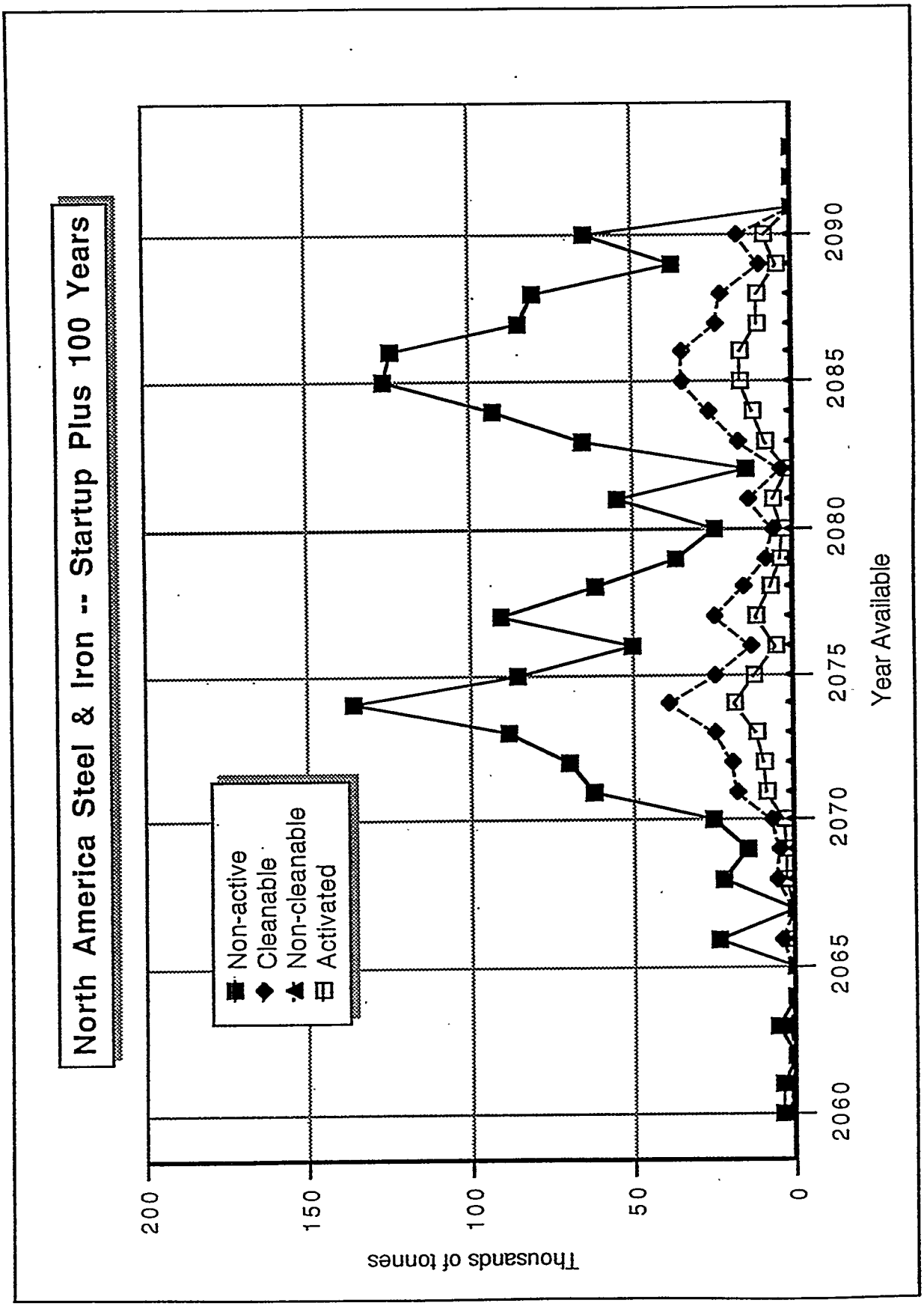


FIGURE B.2 (Cont.) Part B: Start-Up Plus 100 Years

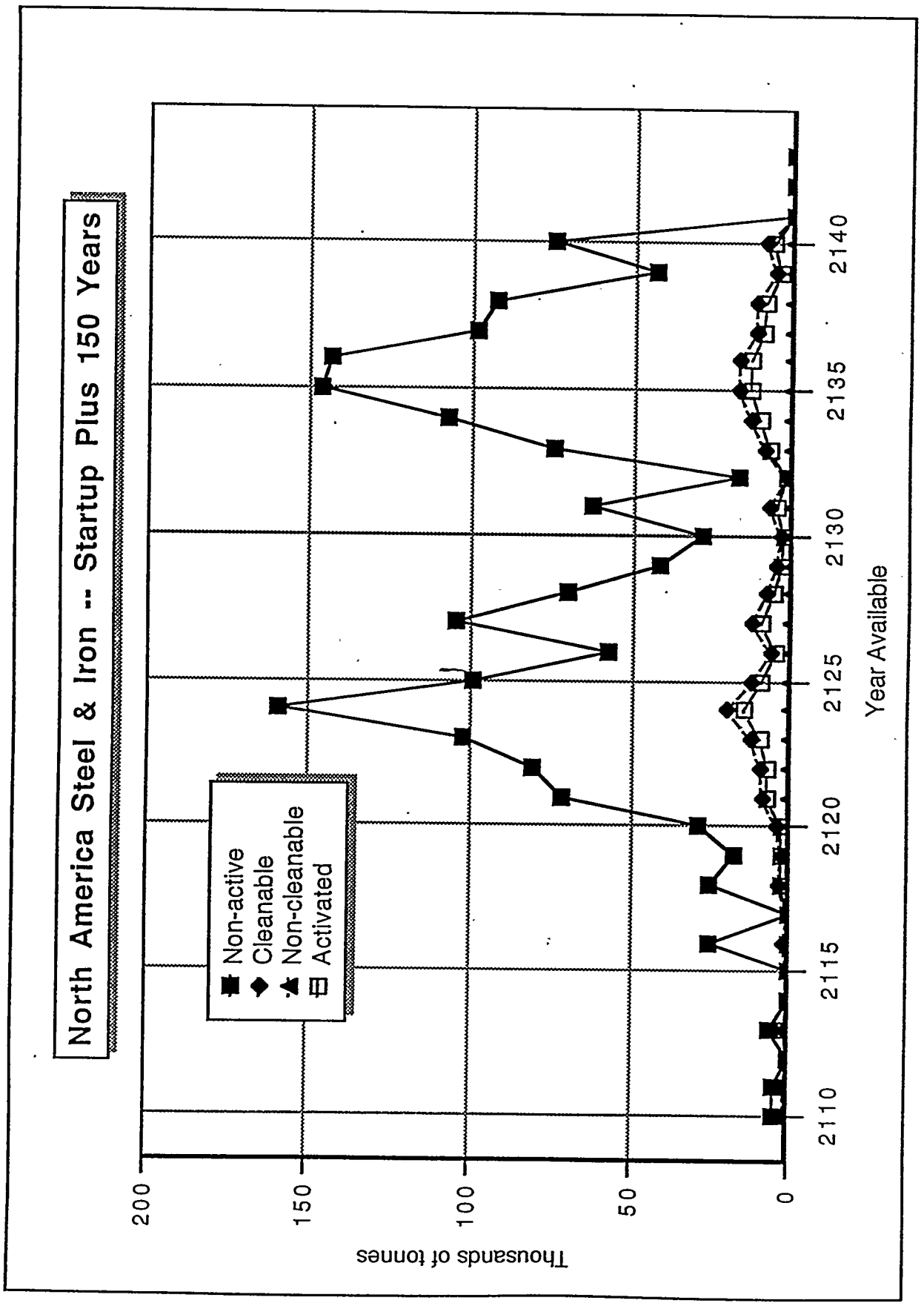


FIGURE B.2 (Cont.) Part C: Start-Up Plus 150 Years

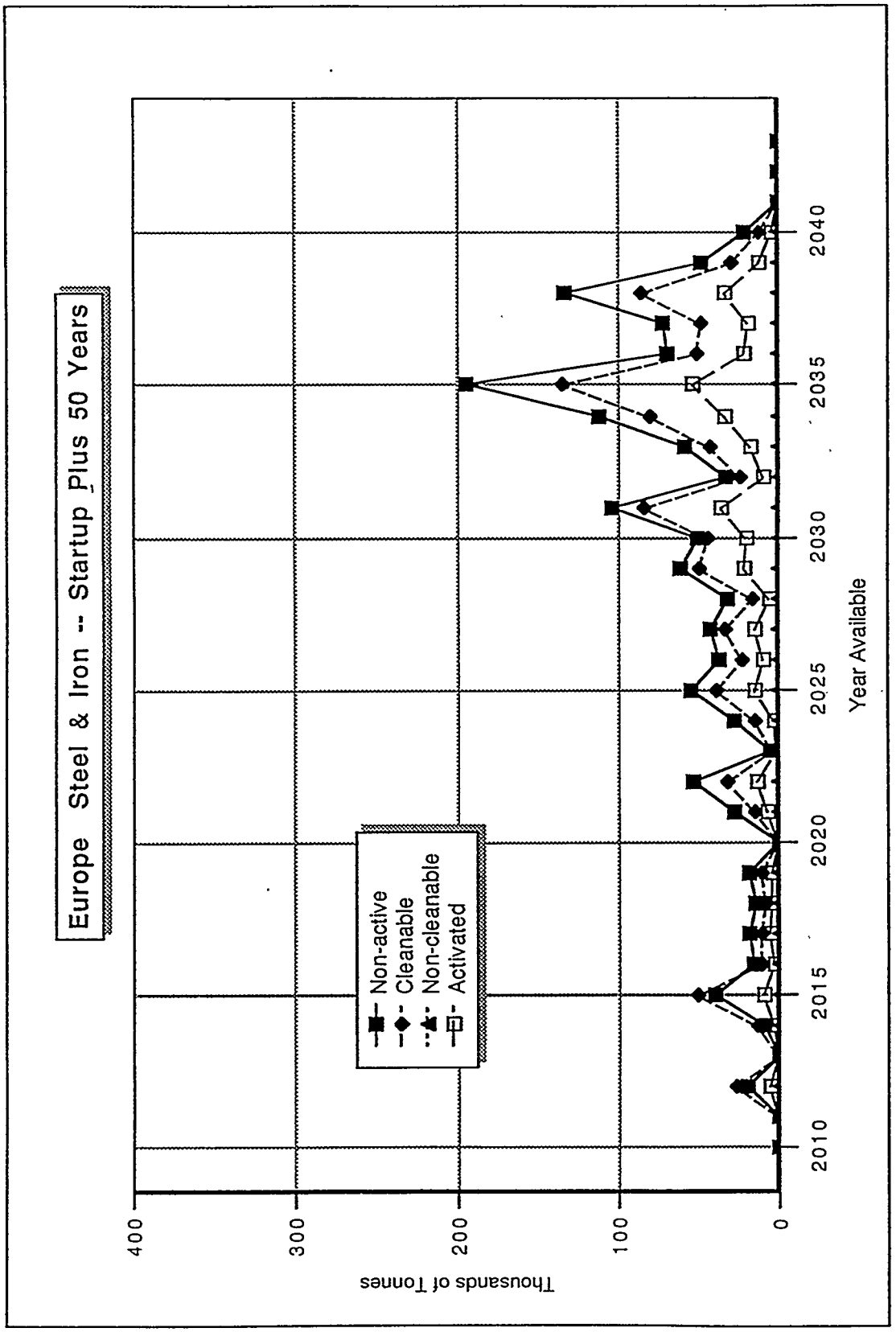


FIGURE B.3 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for Europe (includes eastern Europe: Bulgaria, Czech Republic, Finland, Hungary, Poland, Romania, Slovakia, and Slovenia); Part A: Start-Up Plus 50 Years

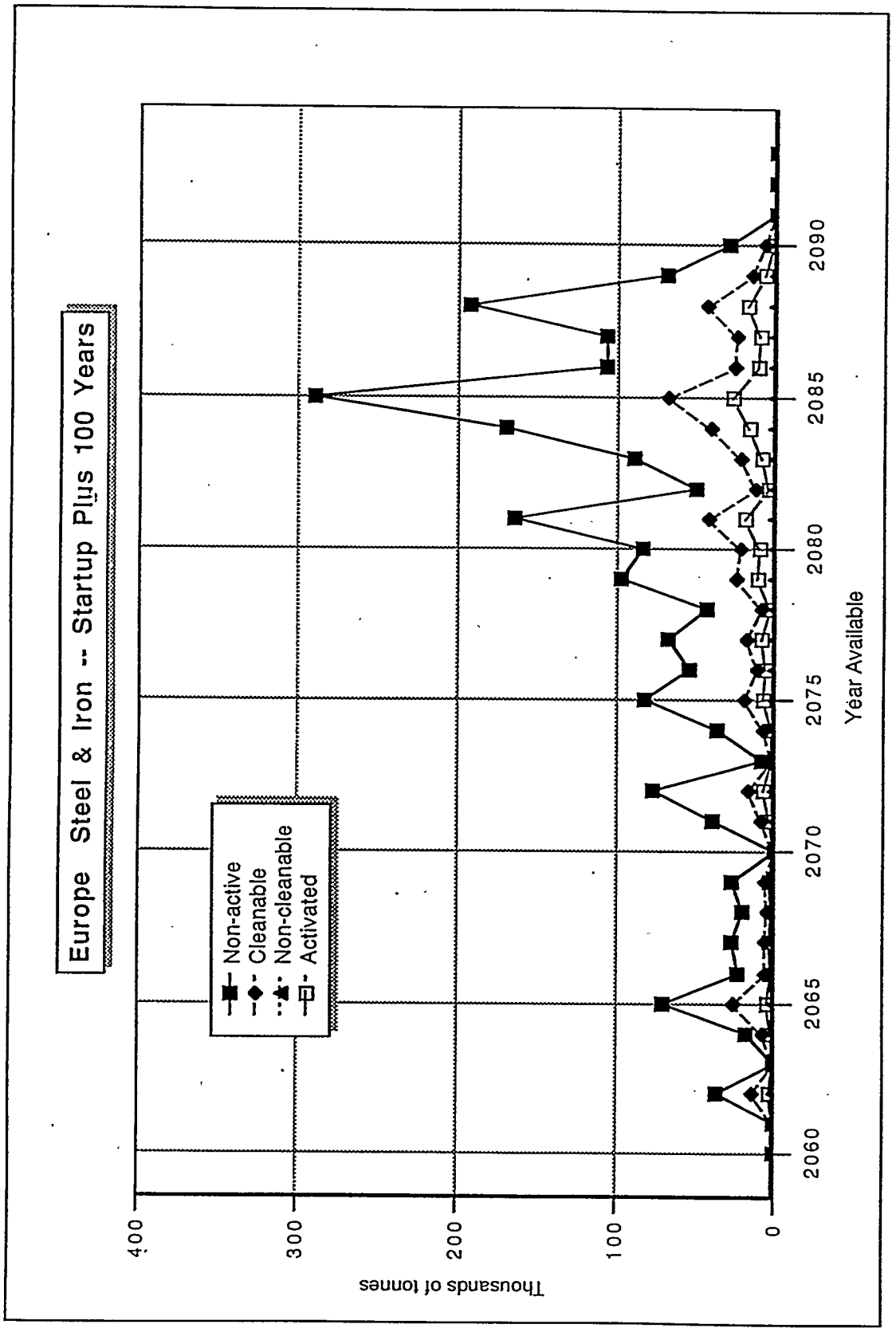


FIGURE B.3 (Cont.) Part B: Start-Up Plus 100 Years

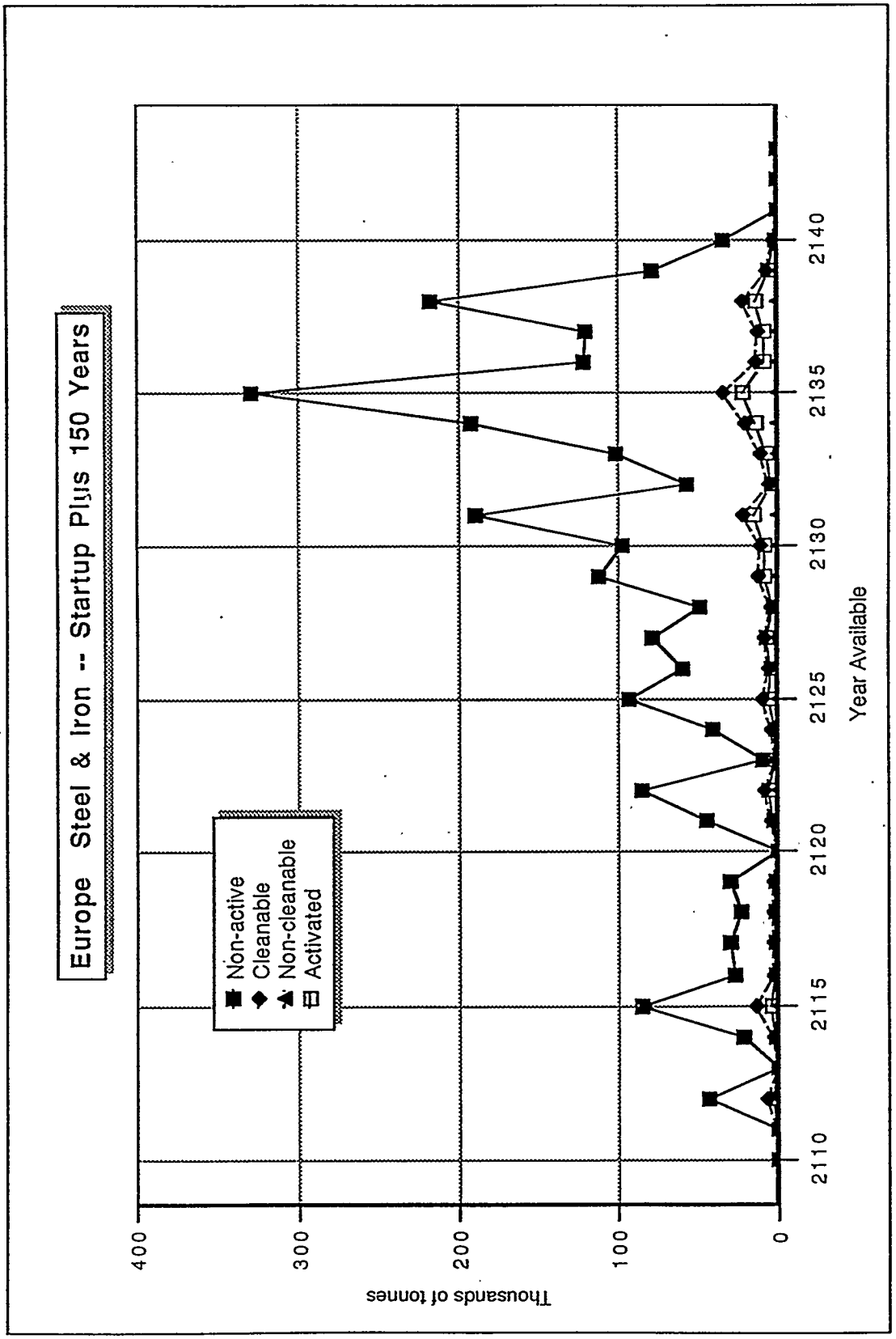


FIGURE B.3 (Cont.) Part C: Start-Up Plus 150 Years

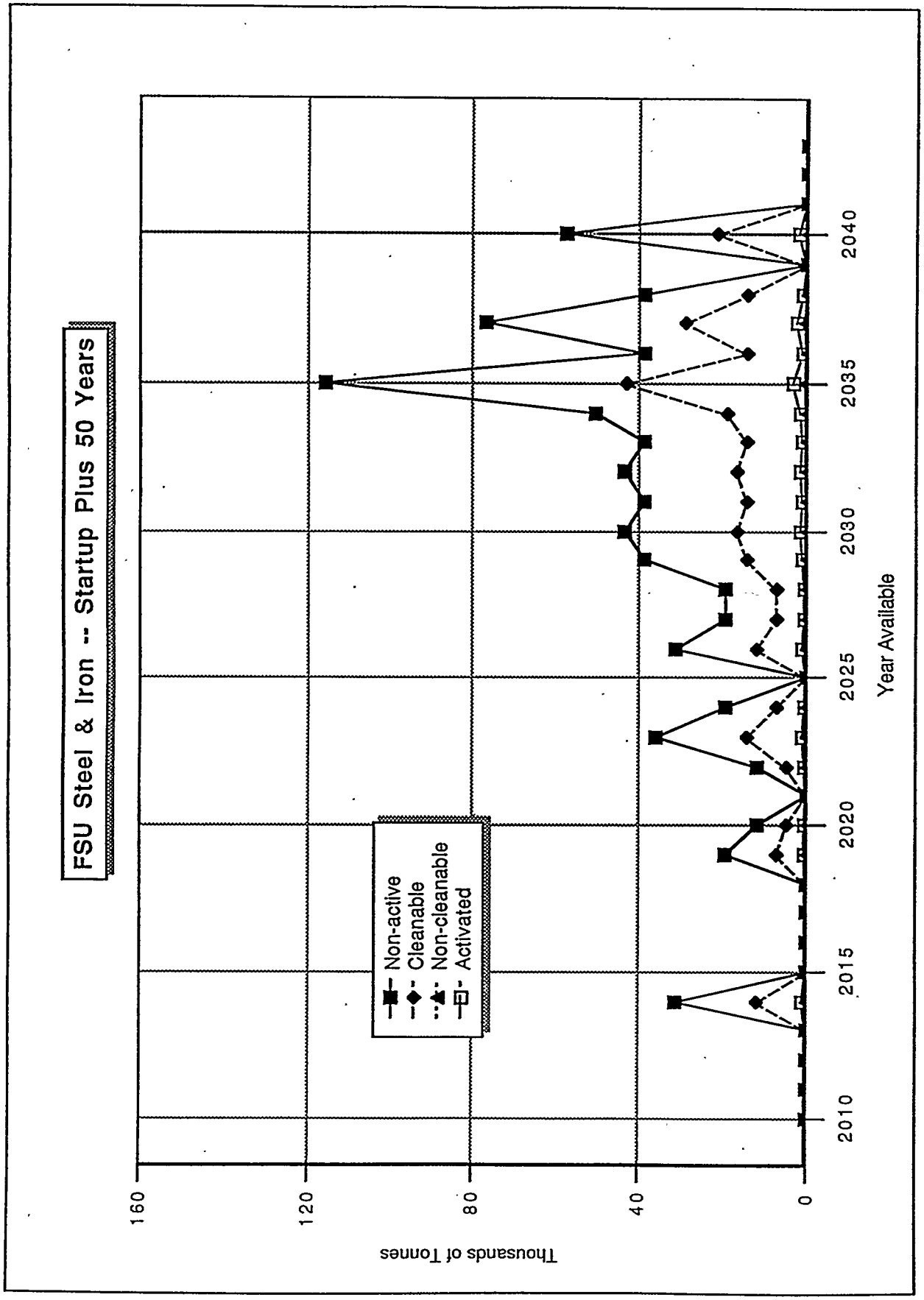


FIGURE B.4 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for the Former Soviet Union (includes Asian parts of the former Soviet Union); Part A: Start-Up Plus 50 Years

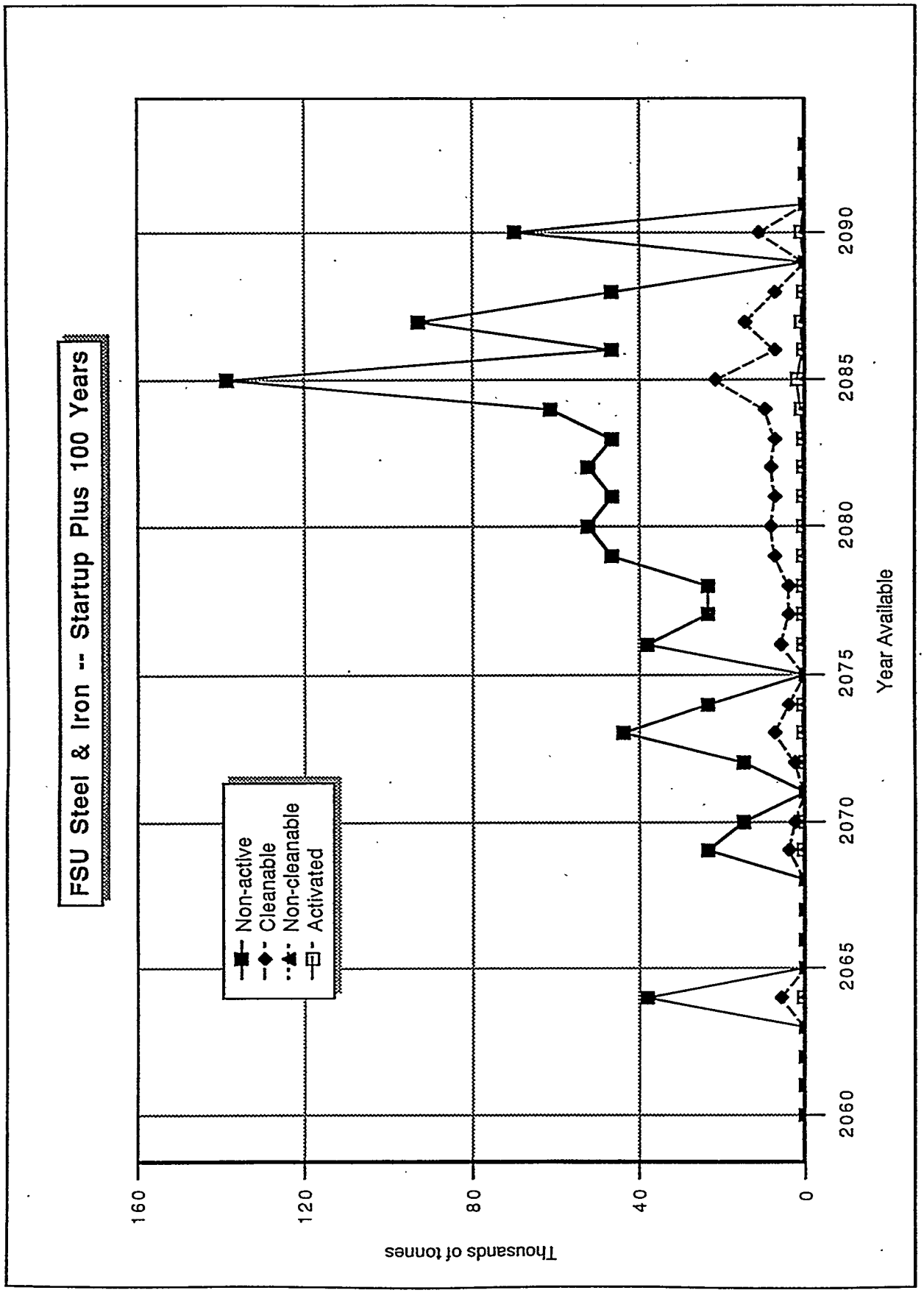


FIGURE B.4 (Cont.) Part B: Start-Up Plus 100 Years

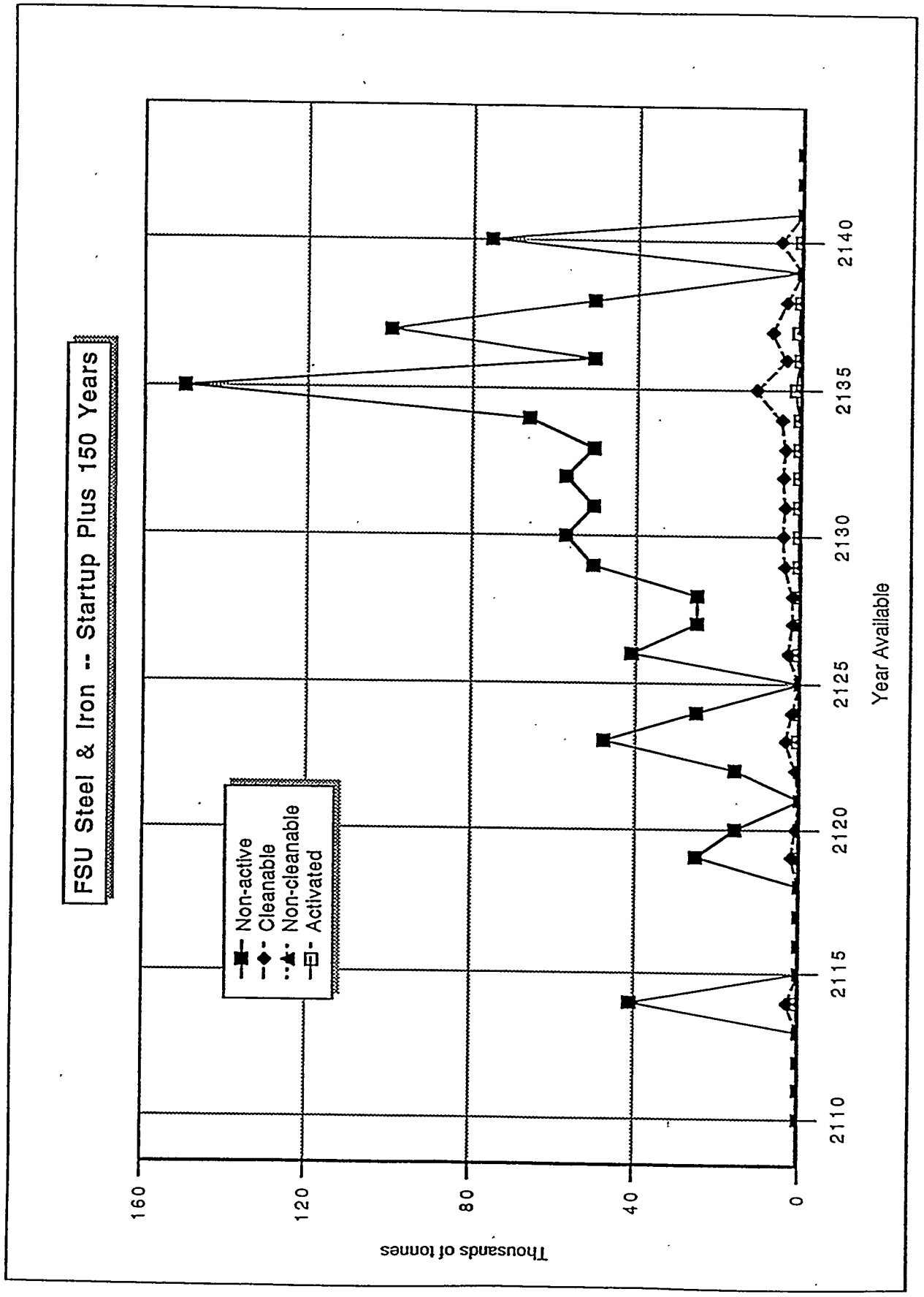


FIGURE B.4 (Cont.) Part C: Start-Up Plus 150 Years

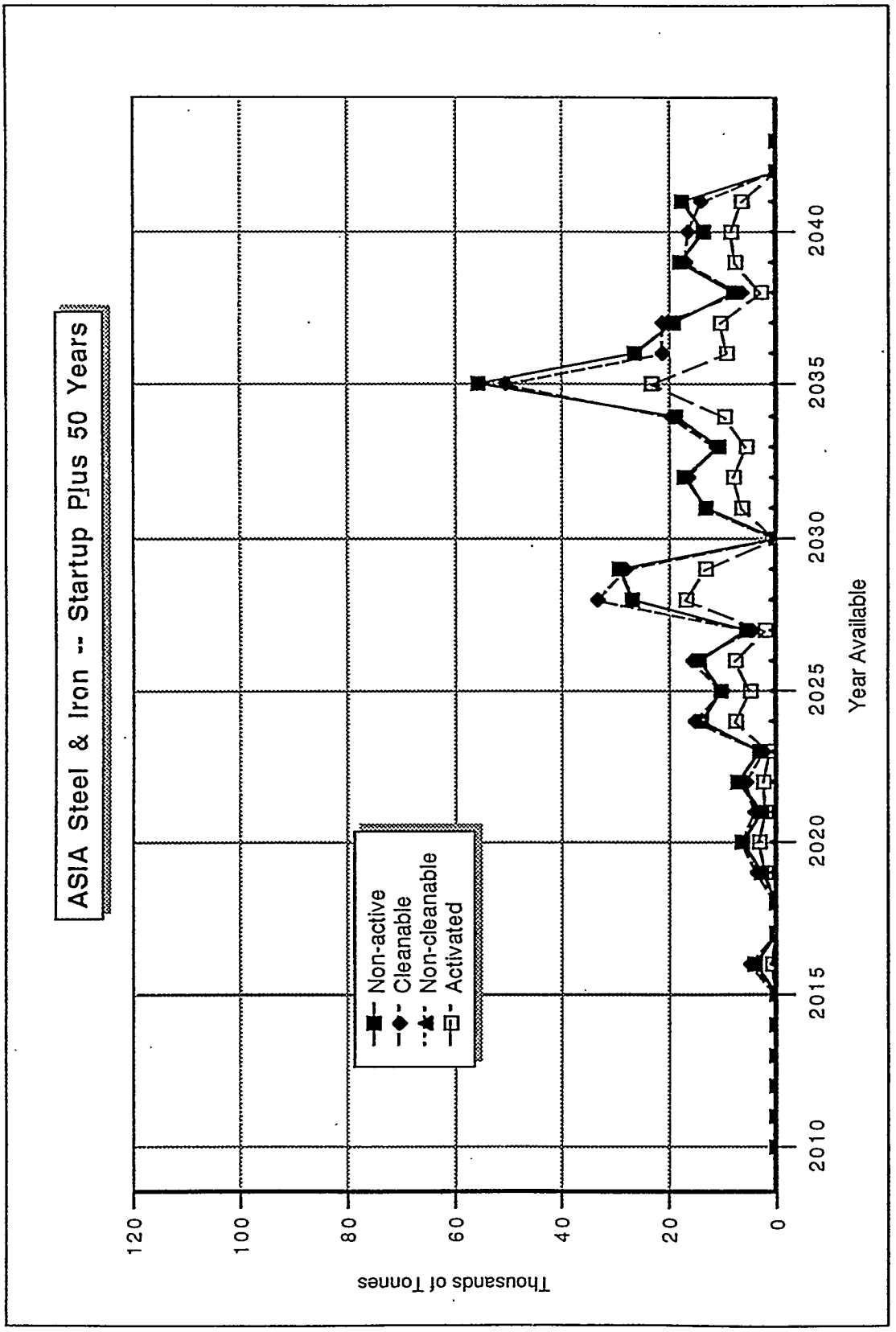


FIGURE B.5 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for Asia (excludes Asian parts of the former Soviet Union); Part A: Start-Up Plus 50 Years

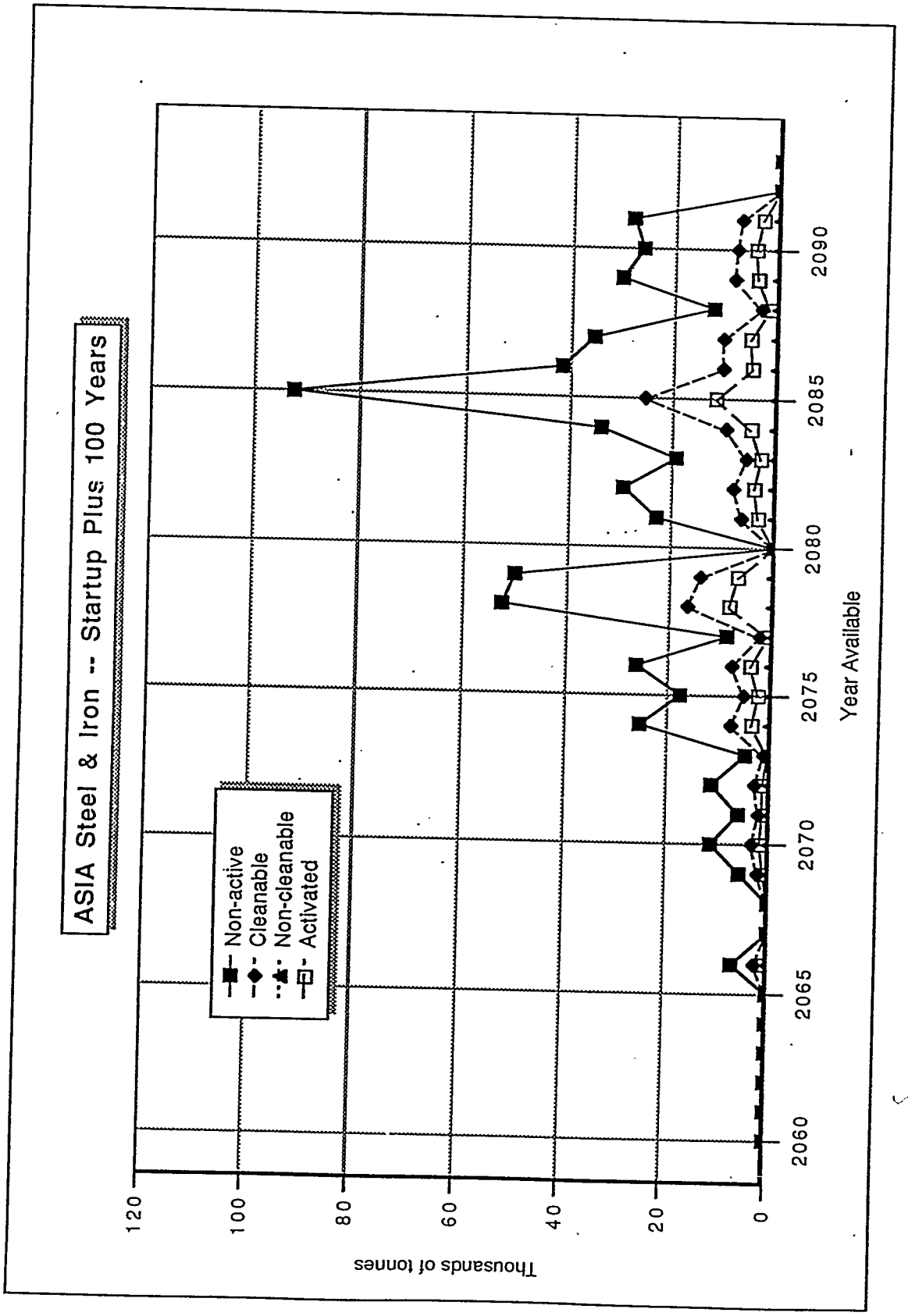


FIGURE B.5 (Cont.) Part B: Start-Up Plus 100 Years

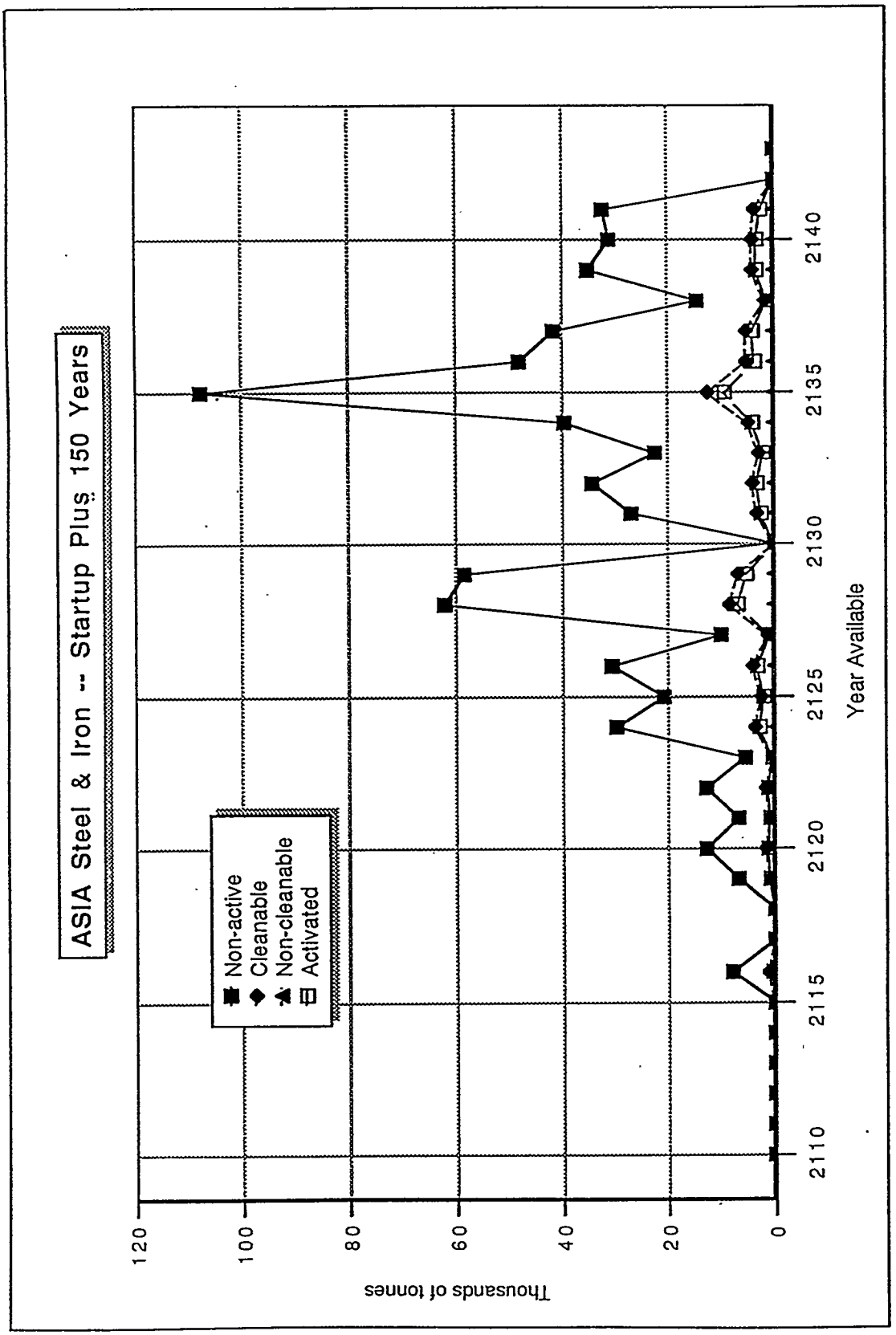


FIGURE B.5 (Cont.) Part C: Start-Up Plus 150 Years

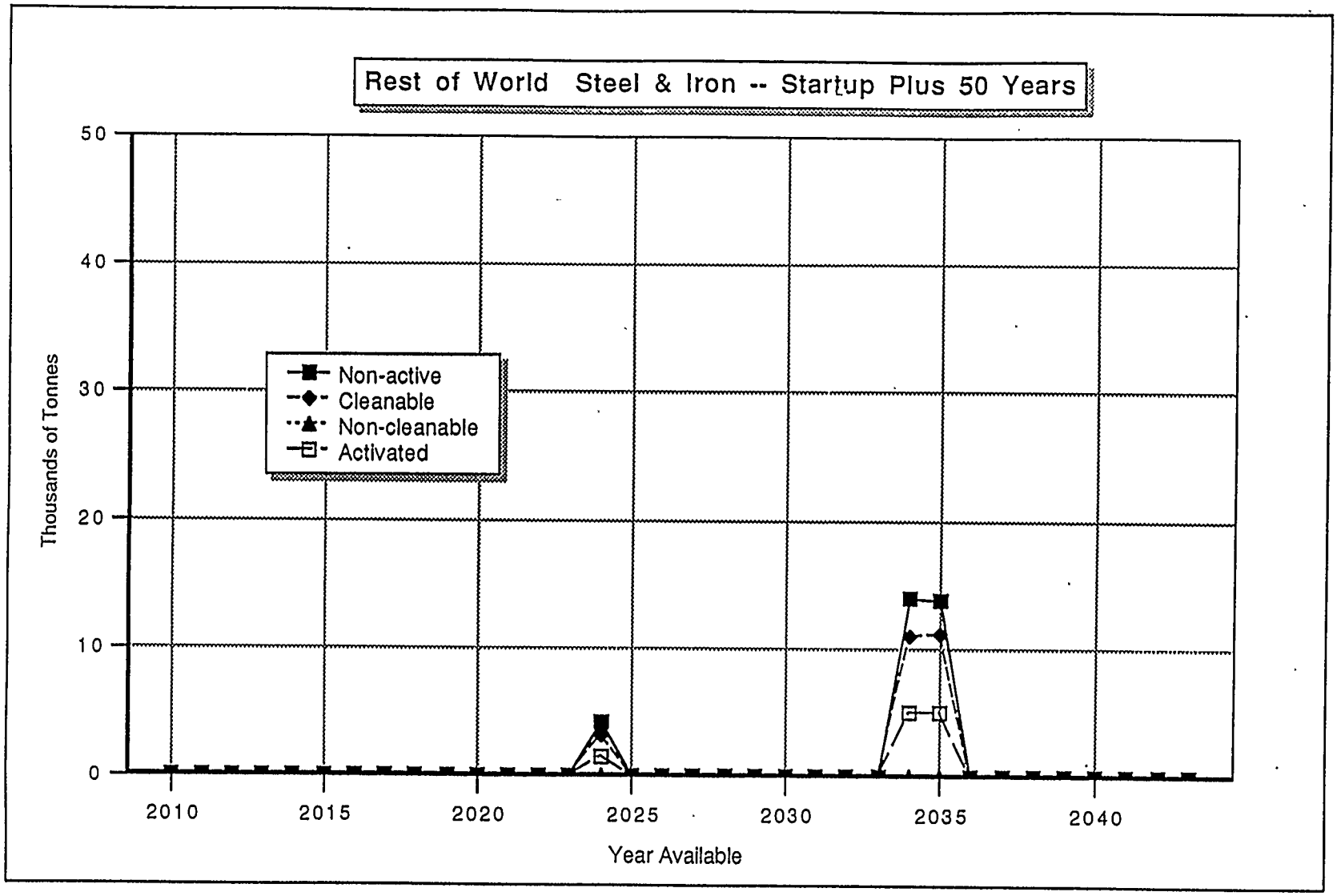


FIGURE B.6 Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants for the Remainder of the World; Part A: Start-Up Plus 50 Years

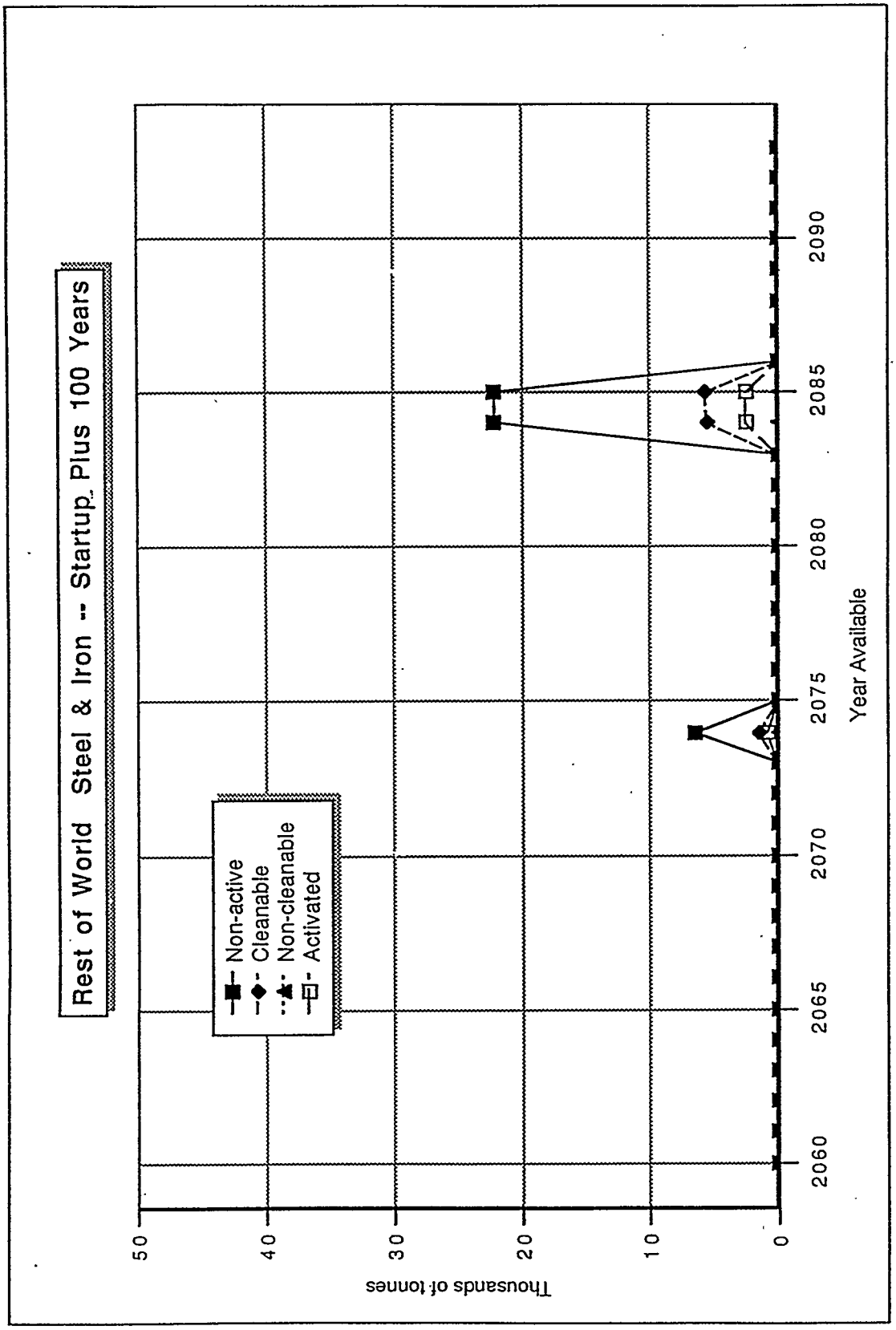


FIGURE B.6 (Cont.) Part B: Start-Up Plus 100 Years

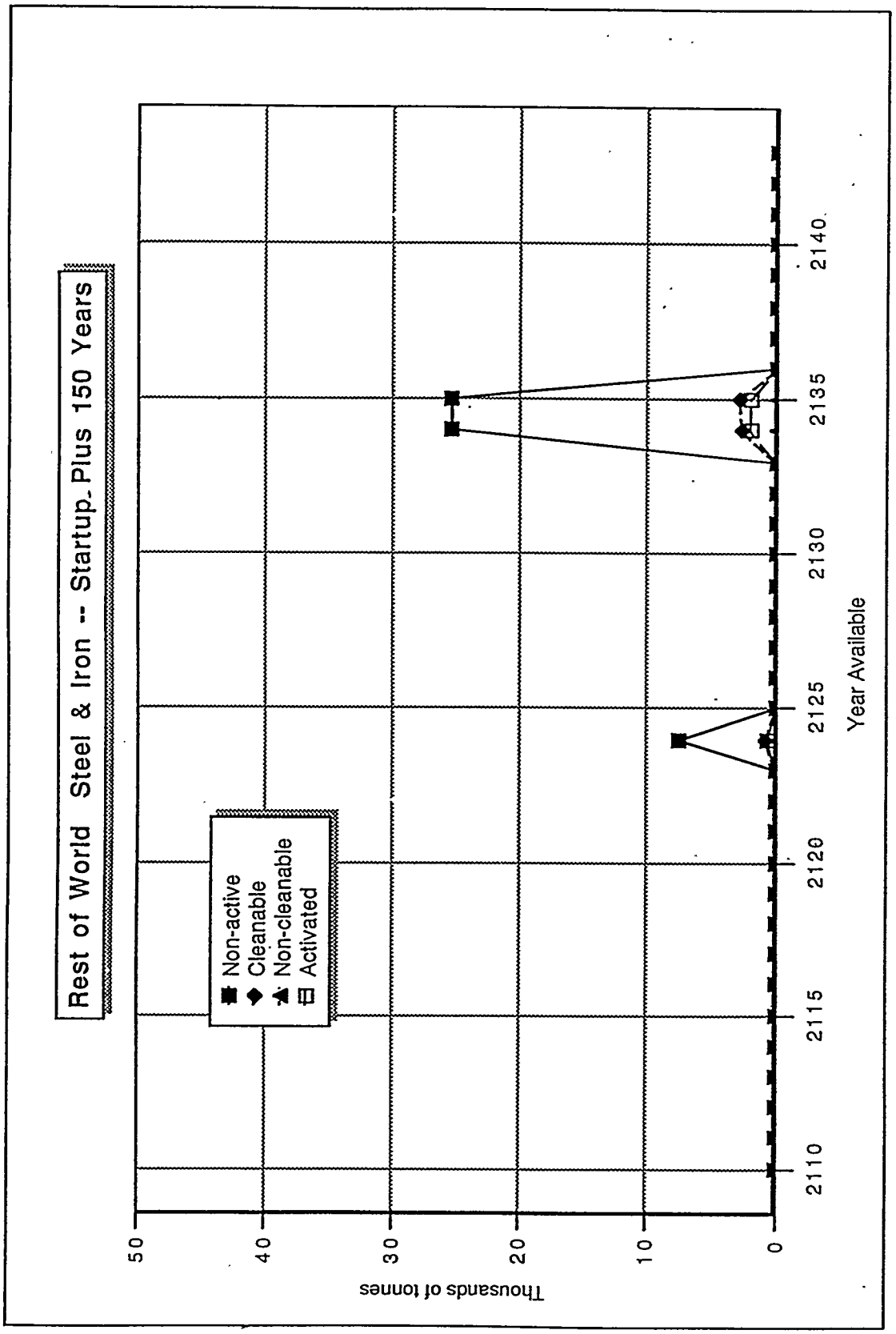


FIGURE B.6 (Cont.) Part C: Start-Up Plus 150 Years

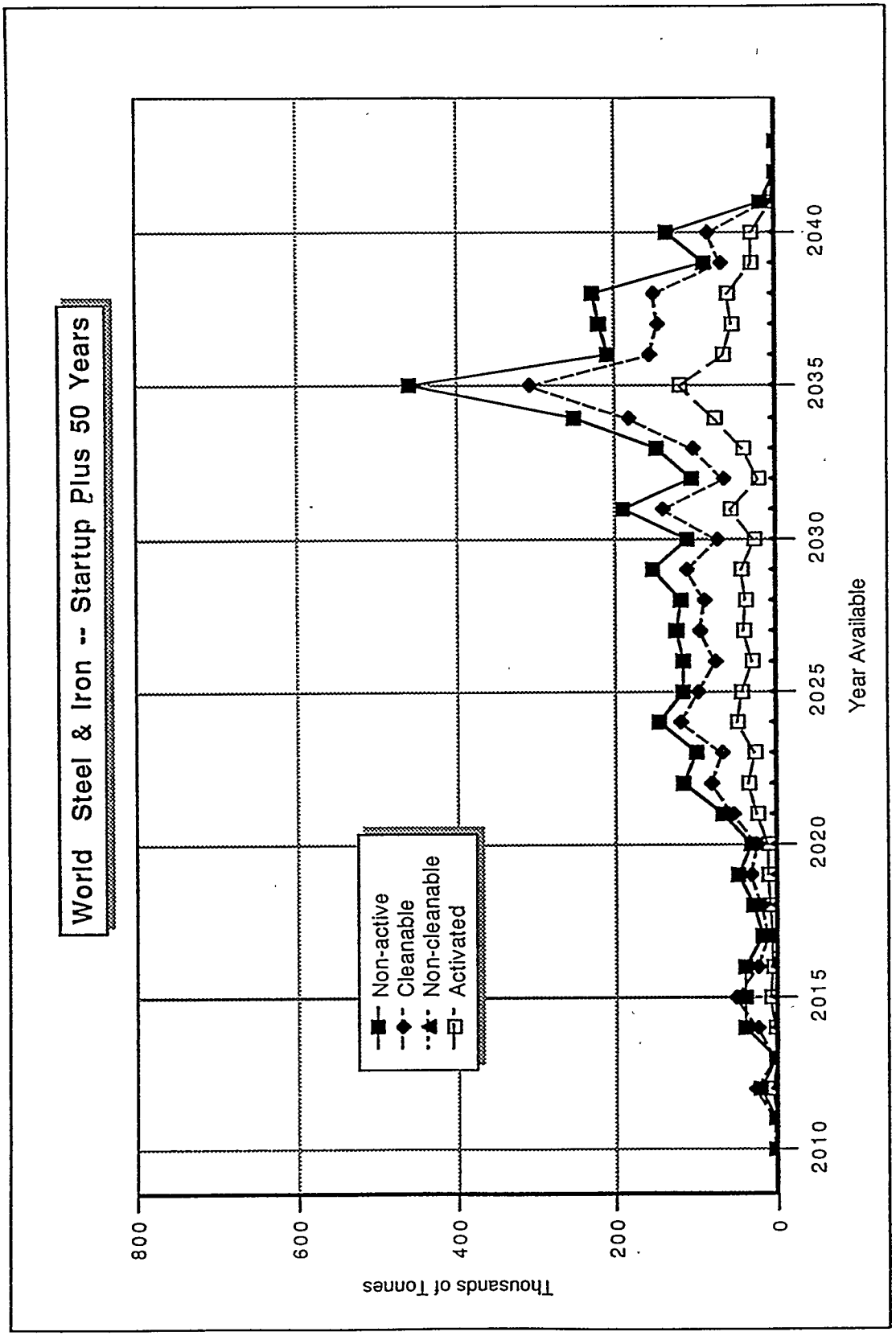


FIGURE B.7 Worldwide Summations of the Annual Increments in Scrap-Metal Inventory from Nuclear Power Plants; Part A: Start up Plus 50 Years

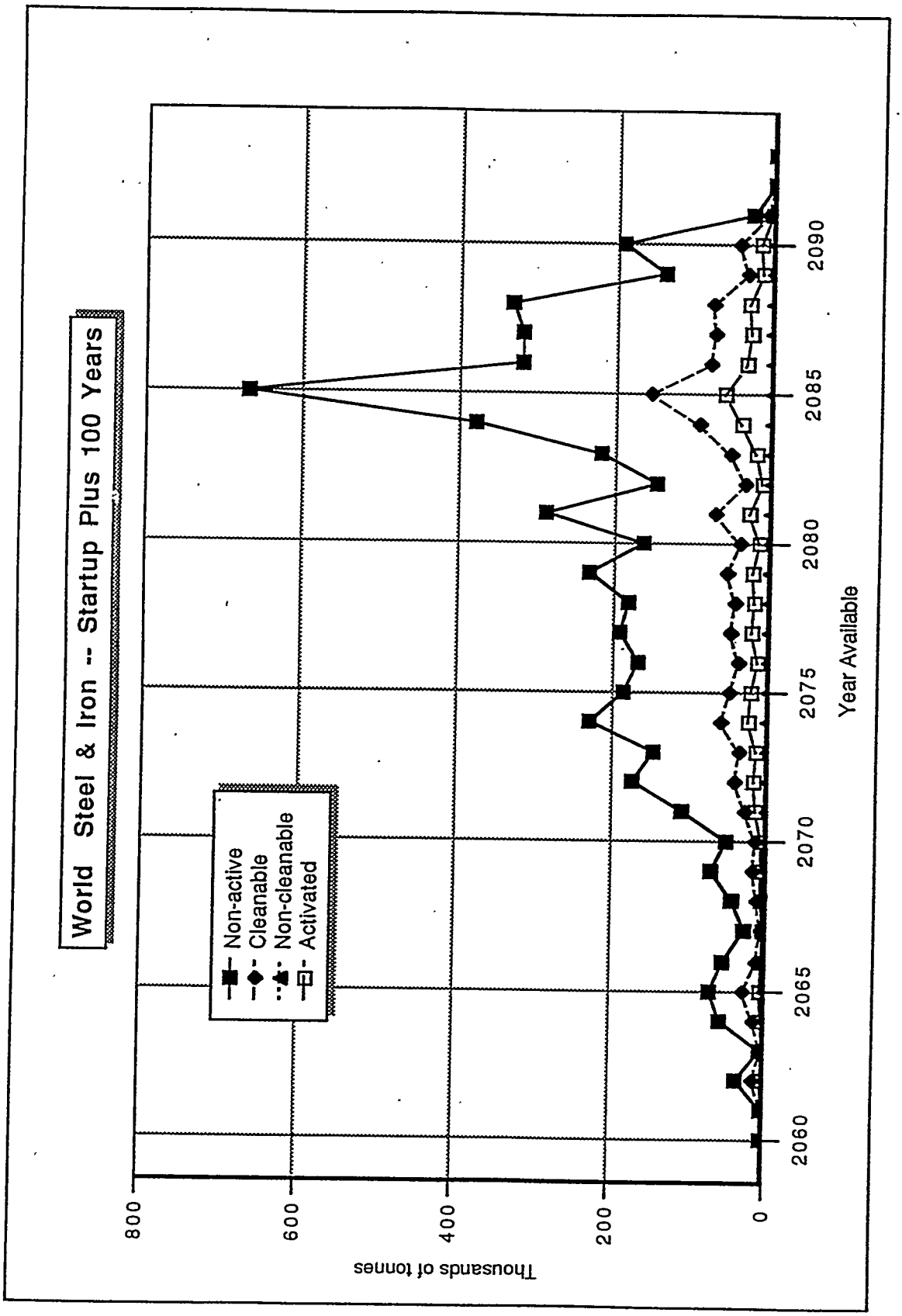


FIGURE B.7 (Cont.); Part B: Start-Up Plus 100 Years

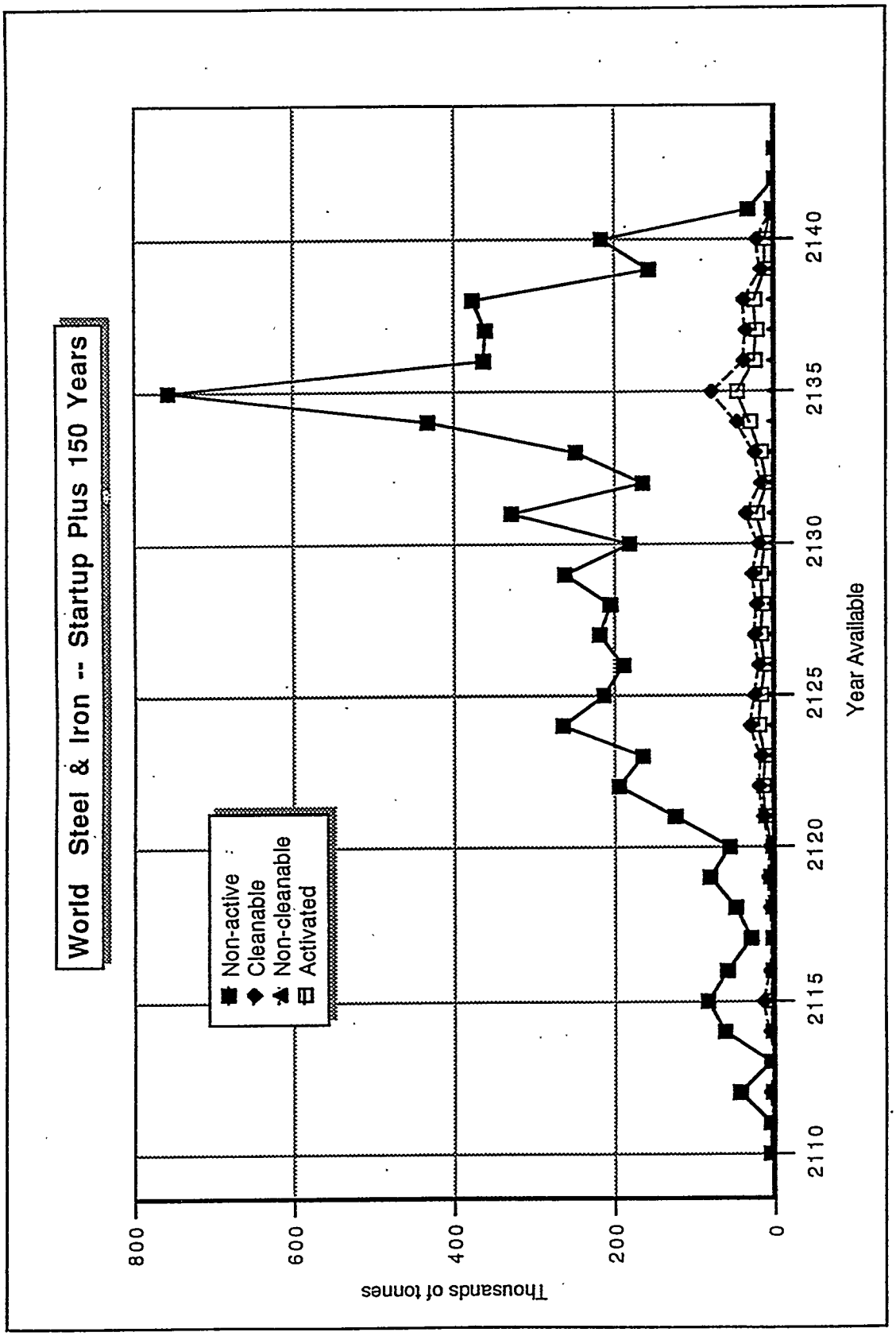


FIGURE B.7 (Cont.); Part C: Start-Up Plus 150 Years

APPENDIX C:

RADIOLOGICAL RISK ASSESSMENT METHODOLOGY AND SENSITIVITY ANALYSIS

APPENDIX C:

RADIOLOGICAL RISK ASSESSMENT METHODOLOGY AND SENSITIVITY ANALYSIS

This appendix first describes the methodology used to calculate doses from radioactive scrap metal (RSM) recycling for the potential release tiers (i.e., Tiers A, B, C, and D). Then the scenarios employed to analyze each tier are described in detail. The method of deriving release levels from the dose estimates is then discussed, followed by an analysis of the sensitivity of dose estimates to important model parameters. Finally, a simulated probabilistic analysis is presented to illustrate the advantages of a Monte Carlo approach in dose assessment.

C.1 RISK ASSESSMENT METHODOLOGY

The basic methodology used for this analysis employs the methods in the U.S. Nuclear Regulatory Commission's (USNRC's) NUREG/CR-5512 publication (USNRC 1992) and the RESRAD-BUILD code developed at Argonne National Laboratory (Yu et al. 1994). While NUREG/CR-5512 is designed to serve as a generic screening model, the RESRAD-BUILD code assesses exposures[1] in a more detailed environmental setting for decontamination and decommissioning activities. For this evaluation, the following pathways were analyzed: inhalation of particulates, radon and its decay progeny, tritium, and volatile elements; ingestion; and external exposure. Exposure assessments for radon, tritium, and volatile elements (such as iodine) were limited to Tier A (reuse scenarios) because of the complexity of assessing these exposures after melting of RSM, which would apply to Tier B and C releases.

For this analysis, consideration was given to radionuclides that have short half-lives. An average decay factor was used to account for radioactive decay over a one-year period in the dose calculations for the public and the workers (Table C.1). The decay factor represents the average fraction of activity present over the course of one year. Inhalation and ingestion doses were calculated with committed effective dose equivalent conversion factors (DCFs) obtained from the U.S. Environmental Protection Agency, Federal Guidance Report No. 11 (Eckerman et al. 1988). These DCFs, which are listed in Table C.1, are based on recommendations in the International Commission on Radiological Protection's (ICRP's) Publication 30 (ICRP 1979-1988), and ICRP Publication 48 (ICRP 1986) for plutonium and related elements. The external effective dose equivalent factors were based on the recent report published by USEPA, Federal Guidance Report No. 12 (USEPA 1993).

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[1] Detailed recycling scenarios and calculation methods have since been incorporated into the RESRAD-RECYCLE code that is under development at Argonne National Laboratory.

TABLE C.1 Inhalation and Ingestion Dose Conversion Factors (DCFs)[a]

Nuclide	Half-Life (yr)	Average Decay Factor[b]	Ingestion DCF (Sv/Bq)	Inhalation DCF (Sv/Bq)
Ac-227	2.18E+01	9.84E-01	3.80E-06	1.81E-03
Ag-110m	6.84E-01	6.29E-01	2.92E-09	2.17E-08
Am-241	4.33E+02	9.99E-01	9.84E-07	1.20E-04
Am-243	7.37E+03	1.00E+00	9.79E-07	1.19E-04
Ca-41	1.03E+05	1.00E+00	3.44E-10	3.64E-10
Ce-144	7.79E-01	6.62E-01	5.68E-09	1.01E-07
Cl-36	3.01E+05	1.00E+00	8.18E-10	5.93E-09
Cm-243	2.85E+01	9.88E-01	6.79E-07	8.30E-05
Cm-244	1.81E+01	9.81E-01	5.45E-07	6.70E-05
Cm-245	8.50E+03	1.00E+00	1.01E-06	1.23E-04
Cm-246	4.75E+03	1.00E+00	1.00E-06	1.22E-04
Cm-247	1.56E+07	1.00E+00	9.24E-07	1.12E-04
Co-57	7.97E-01	6.68E-01	3.20E-10	2.45E-09
Co-60	5.27E+00	9.37E-01	7.28E-09	5.91E-08
Cs-134	2.06E+00	8.49E-01	1.98E-08	1.25E-08
Cs-135	2.30E+06	1.00E+00	1.91E-09	1.23E-09
Cs-137	3.02E+01	9.89E-01	1.35E-08	8.63E-09
Eu-152	1.36E+01	9.75E-01	1.75E-09	5.97E-08
Eu-154	8.80E+00	9.62E-01	2.58E-09	7.73E-08
Fe-55	2.70E+00	8.82E-01	1.64E-10	7.26E-10
Mn-54	8.57E-01	6.86E-01	7.48E-10	1.81E-09
Na-22	2.60E+00	8.78E-01	3.10E-09	2.07E-09
Nb-94	2.03E+04	1.00E+00	1.93E-09	1.12E-07
Ni-59	7.50E+04	1.00E+00	5.67E-11	7.31E-10
Ni-63	1.00E+02	9.97E-01	1.56E-10	1.70E-09
Np-237	2.14E+06	1.00E+00	1.20E-06	1.46E-04
Pb-210	2.23E+01	9.85E-01	1.45E-06	3.67E-06
Pm-147	2.62E+00	8.79E-01	2.83E-10	1.06E-08
Pu-238	8.78E+01	9.96E-01	8.65E-07	1.06E-04
Pu-239	2.41E+04	1.00E+00	9.56E-07	1.16E-04
Pu-240	6.54E+03	1.00E+00	9.56E-07	1.16E-04
Pu-241	1.44E+01	9.76E-01	1.85E-08	2.23E-06
Pu-242	3.76E+05	1.00E+00	9.08E-07	1.11E-04
Ru-106	1.01E+00	7.23E-01	7.40E-09	1.29E-07
Sb-125	2.77E+00	8.85E-01	7.59E-10	3.30E-09
Se-79	6.50E+04	1.00E+00	2.35E-09	2.66E-09
Sm-151	9.00E+01	9.96E-01	1.05E-10	8.10E-09
Sr-90	2.86E+01	9.88E-01	3.85E-08	3.51E-07
Tc-99	2.13E+05	1.00E+00	3.95E-10	2.25E-09
Th-228	1.90E+00	8.38E-01	1.07E-07	9.23E-05
Th-229	7.30E+03	1.00E+00	9.54E-07	5.80E-04
Th-230	7.50E+04	1.00E+00	1.48E-07	8.80E-05
Th-232	1.40E+10	1.00E+00	7.38E-07	4.43E-04
U-232	6.89E+01	9.95E-01	3.54E-07	1.78E-04
U-233	1.60E+05	1.00E+00	7.81E-08	3.66E-05
U-234	2.44E+05	1.00E+00	7.66E-08	3.58E-05

TABLE C.1 (Cont.)

Nuclide	Half-Life (yr)	Average Decay Factor[b]	Ingestion DCF (Sv/Bq)	Inhalation DCF (Sv/Bq)
U-235	7.04E+08	1.00E+00	7.19E-08	3.32E-05
U-238	4.47E+09	1.00E+00	6.88E-08	3.20E-05
Zn-65	6.70E-01	6.23E-01	3.90E-09	5.51E-09
Zr-93	1.50E+06	1.00E+00	4.48E-10	8.67E-08

[a] Internal dose conversion factors were taken from USEPA Federal Guidance Report No. 11 (Eckerman et al. 1988).

[b] Represents the average fraction of activity present over one year.

C.1.1 Radionuclide Selection

Analyses were initially conducted for a comprehensive list of potential contaminants (more than 200 radionuclides). Because of the difficulty of conducting a full analysis for the complete list, representative radionuclides were selected on the basis of the following criteria: (1) radionuclides analyzed in the IAEA and Commission of the European Communities (CEC) reports (CEC 1988) were included; (2) radionuclides with a half-life of less than one year were not included, with the exception of those that were expected to be prevalent in RSM (e.g., Zn-65 and Mn-54); (3) radionuclides with relatively low internal or external dose conversion factors were excluded from the analysis; and (4) results of an analysis of smelted metal from decontaminated reactors were used to focus the selection (Scientific Ecology Group 1993). While it is recognized that the final list of radionuclides presented in this report does not represent the full inventory of radionuclides that may be present in RSM, the results can be used to estimate doses from other radionuclides with similar DCFs.

C.1.2 Surface Contamination Methodology

The reuse scenarios assess exposures to a surface contaminated room or small tool. A room compartment that is 5 × 5 × 3 m is assumed. For extensive contamination, all four walls of the room are assumed to be uniformly contaminated. For small tools/motors, or equipment, a representative area of 1 m^2 is assumed in the same room environment. The RESRAD-BUILD code (Yu et al. 1994) was used to perform the calculations.

C.1.2.1 Inhalation

In calculating the inhalation dose from surface contamination, the RESRAD-BUILD code applies an emission rate of 10^{-6} per hour (Healy 1971) rather than a resuspension factor and accounts for air ventilation rate and total area of the contaminated surface as follows:

$$CEDE_i = C_i \times ER \times IR \times F \times ED \times DCF_i \times A_s \times W/(V \times k) \ , \qquad \text{(C.1)}$$

where

$CEDE_i$ = committed effective dose equivalent from intake of radionuclide i (Sv),

C_i = concentration of radionuclide i on RSM (assumed to be 1 Bq/cm^2),

ER = emission rate (assumed to be 10^{-6}/h [Healy 1971]),

IR = inhalation rate (assumed to be 1.2 m^3/h [ICRP 1975]),

F = average decay factor (unitless),

ED = exposure duration (h),

DCF_i = inhalation dose conversion factor for radionuclide i (Sv/Bq),

A_s = surface area of the source (cm^2),

W = fraction of airborne dust originating from the contaminated source (unitless, assumed to be 1.0),

V = volume of the room (cm^3), and

k = ventilation rate (assumed to be 1/h).

C.1.2.2 Ingestion

The ingestion dose from surface contamination was calculated with the following equation:

$$CEDE_i = C_i \times IG \times ED \times DCF_i \times F \times W \ , \qquad \text{(C.2)}$$

where

IG = rate of ingestion of removable surface contamination,

DCF_i = ingestion dose conversion factor for radionuclide i,

W = fraction of ingested material originating from the contaminated surface (unitless, assumed to be 1).

For the tool reuse scenario, the ingestion dose was multiplied by the ratio of contaminated surface area of the tool to that of the room.

C.1.2.3 Radon

Exposure to radon and its decay progeny is likely to affect workers as well as the public under the reuse scenario. The concentration of radon in air was calculated as follows:

$$C_{ra}(t) = rS\ (A/V)\ [\lambda/(\lambda + k)]\ , \qquad \text{(C.3)}$$

where

$C_{ra}(t)$ = radon concentration in air at time (t) (Bq/cm^3),

r = radon emanation factor,

S = radium surface concentration from either direct contamination or ingrowth from a parent of radium (1 Bq/cm^2),

A = area of the source (cm^2),

V = the volume of the room,

λ = radon decay constant, and

k = building ventilation rate (h^{-1}).

The working level is derived from the concentrations of radon decay products, which are obtained from the concentration and building ventilation rates. A time-averaged concentration is used to evaluate the first-year dose.

C.1.2.4 Volatile Elements

The air concentration of tritium and volatile elements was calculated using the following equation:

$$C_i(t) = S_i\left(\frac{A}{V}\right)\frac{\gamma}{k}\, e^{-\lambda_i t}\ , \qquad \text{(C.4)}$$

where

$C_i(t)$ = concentration of radionuclide i in air at time (t) (Bq/cm^3),

S_i = surface concentration of radionuclide i in RSM (Bq/cm^2),

γ = emission rate (h^{-1}), and

λ_i = decay constant of radionuclide i (h^{-1}).

In this calculation, the radioactivity is assumed to be released in one year.

C.1.2.5 External Exposure

Each contaminated surface in a scenario contributes to the external exposure. The exposure rate depends upon the geometry of the surface relative to the point at which the dose is to be evaluated. This geometry is determined by the area of the source, the distance (parallel and perpendicular to the surface) between the source and receptor, and the shielding between the source and receptor. The Federal Guidance Report 12 (USEPA 1993) surface dose conversion factors for infinite plane sources with the receptor 1 m from the plane and without shielding were used as reference points. The external exposure from surface contamination was derived as:

$$EDE_i = C_i \times T \times \sum_{surfaces} D_{\infty i} \times F_{Gi} \,, \qquad \text{(C.5)}$$

where

EDE = effective dose equivalent for radionuclide (i),

T = time exposed to surfaces,

D_∞ = Federal Guidance Report 12 dose conversion factor for infinite plane source, and

F_G = geometrical factor for finite area, shielding, and position of receptor relative to the surface.

The geometrical factors are obtained by finding the ratio of dose integrals over the source. These dose integrals considered source energy, attenuation, and buildup through cover material and air. Each energy from a radionuclide's decay was considered separately and weighted by its yield. The integral is one-dimensional, assuming the source is cylindrical. Therefore, the dimension to be integrated is the perpendicular distance from the cylinder's axis. This is done as follows:

$$F_G = \frac{\sum_{Energies:\, j} y_j E_j \int_0^R \frac{B(x') \times e^{-\mu x'}}{(x')^2} dA}{\sum_{Energies:\, j} y_j E_j \int_0^\infty \frac{B_a(x) \times e^{-\mu_a x}}{x^2} dA} \qquad \text{(C.6)}$$

where

$$x^2 = r^2 + (1\ m)^2$$

$$(x')^2 = r^2 + (d_a + d_c)^2$$

$$\mu = \frac{d_a \mu_a + d_c \mu_c}{d_a + d_c}$$

$$B(x) = B_a\left(\frac{d_a}{d_a + d_c} x\right)\ B_c\left(\frac{d_c}{d_a + d_c} x\right)$$

(μ and B are the appropriate energy and material (a: air, c: cover material) attenuation coefficient and buildup factor).

C.1.3 Volume Contamination Methodology

C.1.3.1 Inhalation

The dose from inhalation of contaminated airborne particulates from volume-contaminated RSM was calculated as follows:

$$CEDE_i = C_i \times F \times IR \times AD \times W \times ED \times DCF_i\ , \qquad \text{(C.7)}$$

where

C_i = concentration of nuclide i in RSM (assumed to be 1 Bq/g),

AD = airborne dust concentration (g/m^3),

W = the fraction of airborne dust originating from the contaminated source (unitless, assumed to be 1.0).

The critical parameter in this equation is the concentration of respirable dust in air (AD). The value for this parameter depends on a multitude of factors, including ventilation, particle-size distribution, and quantity of material being handled. Because little is known about the amount of respirable dust in air, the parameter is estimated with a mass airborne

dust-loading factor. As a conservative screening approach, the IAEA Safety Series No. 111 report (IAEA 1992) limit for indoor dust (i.e., 1×10^{-3} g/m^3) was used as an upper-bound limit for indoor worker scenarios. A factor of 10 lower was used for scenarios having less potential for resuspension.

C.1.3.2 Ingestion

The CEDE for ingestion was calculated as explained for surface contamination (Section C.1.2.2):

$$CEDE_i = C_i \times F \times IG \times ED \times DCF_i \qquad \text{(C.8)}$$

where

IG = ingestion rate (g/h).

C.1.3.3 External Exposure

Each contaminated volume in a scenario contributes to the external exposure. The exposure rate depends upon the geometry of the volume relative to the point where the dose is to be evaluated. Each volume is represented either as a full or half cylinder. The geometry is determined by the area of the source, thickness of the source, the distance (parallel and perpendicular to the surface) between the source and receptor, and the shielding between the source and receptor. The Federal Guidance Report 12 semi-infinite slab volume dose conversion factors (USEPA 1993) with the receptor 1 m from the plane without shielding were used as reference points. Corrections for finite thickness of the source were made on the basis of the methodology in Chen (1991a,b). The external exposure from contaminated volumes was derived as:

$$EDE_i = C_i \times T \times \sum_{surfaces} D_{\infty i} \times F_{Gi} \qquad \text{(C.9)}$$

where

EDE = effective dose equivalent for radionuclide (i),

T = time exposed to surfaces,

D_∞ = Federal Guidance Report 12 dose conversion factor for semi-infinite volume source,

F_G = geometrical factor for finite area, source thickness, shielding, and position of receptor relative to the surface for radionuclide i.

C.1.4 Disposal Scenario Methodology

The RESRAD code was used to evaluate doses from disposal of surface-contaminated material (Yu et al. 1993b). For volume-contaminated material, the radionuclides are not immediately available for leaching but instead become available for leaching throughout a 100-year corrosion process. This scenario cannot be directly modeled with RESRAD. Instead, the dose was estimated for this scenario by separating the exposure into components from the uneroded material, Q, and the eroding material dQ/dt. The intact material contributes to the dose only through the external pathway, while the eroding material contributes through all pathways. Ingrowth and decay must be considered in both of these components. The time-dependent total dose profile ($D_i(t)$) for a unit source of radionuclide i available for leaching can be calculated from RESRAD. The external component of this at time of deposition is D^{ext}. The dose from contamination of radionuclide j with a decay chain that includes radionuclides i can be expressed as:

$$D(t) = \sum_{i:chain} \left[D_i^{Ext}\, Q(t)\, C_j\, B_{ij}(t) + D_i * \left(\frac{dQ}{dt}\, C_j\, B_{ij}(t) \right) \right], \qquad \text{(C.10)}$$

where the B function is the Bateman's ingrowth (Yu et al. 1993b), decay factor C is the original concentration of contamination, and the symbol "*" designates a time convolution between the two time-dependent functions.

C.1.5 Collective Dose as a Function of Throughput

The number of full-time workers (working 2,000 h per year) used in the collective dose calculations can be modified to account for variation in the amount of RSM to be recycled, according to the following equation:

$$N = N_0 \times (ED_0 \,/\, 2000\ h) \times (M/M_0)\ , \qquad \text{(C.11)}$$

where

N = the number of full time workers,

N_0 = the number of workers in the baseline calculation,

ED_0 = worker exposure duration used in the baseline calculation (h),

M = amount of RSM to be recycled (t), and

M_0 = amount of RSM used in the baseline calculation (100 t).

For example, to recycle 50,000 t of RSM, the number of full-time workers (working 2,000 h per year) can be calculated with the above equation as shown in Table C.2. For end-use scenarios, the number of exposed consumers can be modified to account for variation in the amount of RSM recycled by multiplying the number in the baseline calculation by the ratio of the new amount to the baseline amount of 100 t. For example, to obtain the number of exposed individuals from recycling 50,000 t of RSM, the baseline numbers are multiplied by 500.

C.2 DESCRIPTION OF SCENARIOS

This section describes the scenarios considered for each recycling activity. Representative exposure scenarios were considered for each step in the recycle process and for each major type of steel end use. In general, the exposure scenarios are similar to those presented in the International Atomic Energy Agency (IAEA) Safety Series 111 report (IAEA 1992). The worker scenarios were developed to model potential exposures associated with the transport of RSM from the place of origin to the smelter, the smelting process, and the fabrication and distribution of products. A modified conservative case (described in Section C.4.1) was developed to provide results under realistic assumptions.

The consumer scenarios were developed to model potential doses associated with the unrestricted release tiers. Tier A is represented by a building reuse scenario, which models potential exposures from reuse of a surface-contaminated room, and by a scenario for reuse of a small object or item of equipment. Eight consumer product scenarios are modeled under Tier B, and two scenarios were developed to model potential exposures from specified-initial-use products for Tier C. For the restricted recycle option, Tier D, three end-use exposure scenarios were developed.

C.2.1 Worker Scenarios

The parameter assumptions used in modeling each scenario are listed in Table C.2. The results of the analysis are presented for each scenario in Tables D.1 through D.22 (Appendix D). The results are represented in terms of individual dose and also collective dose for a 100-t throughput..

C.2.1.1 Scrap Delivery

Two scenarios are considered for the scrap delivery recycle step: loader and truck driver. The loader scenario models the potential doses to an individual who loads the RSM (which has met release limits) onto trucks for transport to the smelter. Standard mechanical loading equipment is assumed to be used for this operation. The truck driver scenario models the potential doses to an individual who transports the RSM from the place of origin to the processing facility. Because the driver would not be directly in contact with the scrap metal,

TABLE C.2 Exposure Parameters Used to Model Worker Scenarios

Recycle Shop	Scenario	Source Geometry	Density (g/cm^3)	Thickness (cm)	Radius (cm)	Distance (cm)	Time (h)	Concentration (Bq/g)	Internal Pathway[a]	Air Concentration (g/m^3)	No. of Workers for 100 t	No. of Full-Time Workers for 50,000 t
Scrap delivery	Loader	1 half cylinder	3.93	253	127	400	4	1	inh, ing	1.E-04	2	2
	Truck driver	1 half cylinder	3.93	900	60	200	4	1	----	----	5	5
Scrap segmenting	Cutter	1 half cylinder	3.93	60	30	200	12	1	inh, ing	1.E-04	3	9
Scrap processing	Processor	1 half cylinder	5.90	60	30	200	12	1	inh, ing	1.E-04	3	9
Smelting	Worker	1 half cylinder	5.90	351	175	1,000	80	1	inh, ing	1.E-04	10	200
	Loader	1 half cylinder	5.90	279	139	400	4	1	inh, ing	1.E-03	5	5
	Operator	1 full cylinder	7.86	253	127	300	5	1	inh, ing	1.E-03	3	3.75
Baghouse	Processor	1 full cylinder	2.00	100	40	200	0.16	100	inh, ing	1.E-03	1	0.04
Industrial products	Ingot caster	1 full cylinder	7.86	100	64	150	2.5	1	inh, ing	1.E-03	2	1.25
	Small objects Caster	1 full cylinder	7.86	1	201	100	50	1	inh, ing	1.E-03	2	25
	Slag worker	1 half cylinder	2.70	45.5	228	150	25	10	inh, ing	1.E-03	1	6.25
	Loader	1 half cylinder	7.86	100	201	400	2	1	----	----	2	1
	Truck driver	1 full cylinder	7.86	200	64	200	5	1	----	----	5	6.25
Initial fabrication	Yard worker	1 half cylinder	7.86	100	201	1,000	40	1	----	----	10	100
	Sheet worker	1 half cylinder	7.86	0.2	138	100	1	1	inh, ing	1.E-04	15	3.75
	Coil worker	1 full cylinder	7.86	122	60	150	1	1	inh, ing	1.E-04	1	0.25
Final fabrication	Sheet worker	1 half cylinder	7.86	0.2	138	100	1	1	----	----	20	5
	Coil worker	1 full cylinder	7.86	122	60	150	80	1	----	----	5	100
Distribution	Loader	1 half cylinder	7.86	100	201	400	20	1	----	----	2	10
	Truck driver	1 full cylinder	7.86	200	64	200	8	1	----	----	5	10
	Sheet worker	1 half cylinder	7.86	0.2	138	100	20	1	----	----	20	100
	Warehouse worker	1 half cylinder	7.86	1.2	138	600	2,000	1	----	----	5	2,500

[a] inh = inhalation; ing = ingestion.

only the external gamma pathway is considered. The calculations do not account for shielding provided by the truck cab.

C.2.1.2 Scrap Cutting

An initial cutting step is modelled when the scrap first enters the processing facility. It is estimated that three individuals would work 12 hours each to process 100 tons of scrap metal. Cutters are assumed to work in an open area. Therefore, the average dust concentration is not expected to be high, although localized high concentrations may occur. Individuals using a torch to perform cutting operations are likely to be wearing some protective equipment. Although a respirable fraction of 1 is assumed, a high percentage of the particulates are expected to be above the respirable range (greater than 10 μm).

C.2.1.3 Scrap Processing

The scrap processing step is represented by an individual who prepares the scrap for input to the furnace. This individual's activities include shredding, cutting, smashing, chopping, bailing, and banding the scrap metal.

C.2.1.4 Smelting of Scrap Metal

Three scenarios are considered for the smelting process: a yard worker, loader, and an operator. The yard worker scenario models potential doses to an individual who works at the storage yard at the smelter. The loader scenario models the potential doses to a crane operator who loads scrap metal into the smelter. The operator scenario models the potential doses to an operator who works at a 100-t furnace.

C.2.1.5 Baghouse Processor

A baghouse processor scenario (based on Elert and Wiborgh [1992]) is evaluated to model potential doses to a worker handling smelter baghouse contents. The dust in the baghouse is assumed to be sprayed with water before handling to reduce the possibility of baghouse dust resuspension and inhalation. The baghouse processor is assumed to conduct his or her activity in the general area of smelting operations, and the dust concentration in the facility is assumed for the calculation of inhalation dose.

The volume of dust generated at a smelter is typically about 1% of the throughput. Thus for a 100-ton throughput, 1 ton of dust is expected to accumulate in the baghouse. Because of the concentrated activity in the dust, the processor is exposed to an activity concentration as high as 100 times the concentration in the scrap metal. The content of the baghouse is typically loaded in 1-ton bags for processing or storage. One processor is assumed to spend 0.16 hour processing dust bags for dust generated from a throughput of 100 t of radioactive scrap metal. This operation will not require a full-time worker for

50,000 t and is conducted at various times per year, depending on the annual throughput. In addition, the quantity handled is small (1%) compared with the quantity of slag (10%).

C.2.1.6 Industrial Products/By-Product

For the industrial products/by-product step, exposures from casting metal ingots or small objects are evaluated, as is exposure to the by-product material (slag). Also included in this step are exposures to those workers involved in transport of the industrial products from the smelting facility to the fabrication plant. The ingot caster scenario is evaluated to model potential doses to a worker casting 10-ton ingots. This scenario is the same as the Caster 1 scenario in the IAEA Safety Series 111 (IAEA 1992). The small objects caster scenario models potential doses to a worker casting industrial or consumer products. This scenario corresponds to the Caster 3 scenario in IAEA Safety Series 111.

The slag worker scenario models the potential doses to a worker who handles the slag. It is estimated that 10 t of slag will be generated from smelting 100 t of RSM. In the base case, the radionuclide concentration in the slag is estimated to be 10 Bq/g, based on the assumption that 10% of the initial charge becomes slag and that all of the radionuclides are concentrated in the slag. This assumption is only valid for some of the radionuclides, and partitioning factors are applied in the modified-conservative case. The loader scenario models the potential doses to a worker at the smelter who loads the industrial products for transport to the fabrication plant. The truck driver scenario models the potential doses to an individual who transports the ingots to the fabrication facility. Shielding from the truck cab is not considered in the dose calculations.

C.2.1.7 Fabrication

The process of fabricating sheet steel materials is divided into initial fabrication and final fabrication. The initial fabrication recycle step considers a yard worker at the fabrication plant, a sheet worker, and a coil worker. A sheet worker and a coil worker were also evaluated for the final fabrication process. The yard worker scenario models the potential exposures to a worker who processes the metal ingots at the steel fabrication plant. The coil worker scenario evaluates the potential doses to a worker who handles coils of sheet steel. Because of the different exposure conditions, inhalation and ingestion are considered plausible and evaluated under the initial fabrication step only.

C.2.1.8 Distribution of Final Products

This recycle step considers the transport and distribution of the final products made at the fabrication facility. Since this recycle step involves the finished product, only external gamma exposure is considered. The loader scenario models potential exposures to an individual who loads and unloads trucks for distribution of the final products. The truck driver scenario models potential exposures to an individual who transports the finished

products for distribution. The sheet worker scenario models potential exposures to an individual who assembles the sheets of steel for a building. The warehouse worker scenario models potential exposures to an individual who is responsible for distribution of consumer products.

C.2.2 Description of End-Use Scenarios

This section describes the end-use scenarios considered. Table C.3 lists the parameter assumptions used in modeling each scenario for Tiers A, B, C, and D. The results of this analysis, which are reported in Appendix D, Tables D.23 through D.35, are given as individual annual committed effective dose equivalent. The committed collective dose equivalent is also reported.

C.2.2.1 Tier A: Unrestricted Reuse

Tool reuse and building occupancy scenarios are modeled for Tier A and shown in Tables D.23 and D.24. The tool reuse scenario considers the use of a small surface-contaminated tool. The tool is treated as having a total surface area of 1 m^2. A building ventilation rate of 1/h is applied. The building occupancy scenario considers the use of a surface-contaminated room. The room size is 5 × 5 × 3 m. Each wall is modeled as a half cylinder with a 3-m radius. An individual is assumed to be located 1 m from one wall, 4 m from the opposite wall, and 1.5 m from the two adjacent walls. The radon emanation factor is conservatively taken to be 1.0 in these scenarios.

C.2.2.2 Tier B: Unrestricted Recycle End-Use Scenarios

This section describes the consumer products scenarios considered under Tier B and the assumptions for the population dose calculations. The amount of steel available for manufacturing consumer products from recycling 100 t of RSM is taken to be 90 t, and the amount of slag is taken to be 10 t (i.e., 10% of the recycled RSM). The steel is assumed to be distributed to various industries in the following proportions (U.S. Bureau of Mines 1985): office/room, 38%; appliance, 8%; automobile, 30%; office furniture, 8%; home furniture, 8%; frying pan, 8%.

The total collective dose from all consumer products scenarios (see Tables D.25-D.29 in Appendix D) is based on a 100-t RSM throughput. Dilution of steel is not in the baseline analysis except for the use of slag (by a factor of 100 with concrete). In the modified-conservative case, both dilution and partitioning factors are included.

TABLE C.3 Exposure Parameters Used to Model Surface Reuse, Consumer Products, Specified Initial Use, and Controlled Recycle Scenarios

Recycle Step	Scenario	Source Geometry	Density (g/cm^3)	Thickness (cm)	Radius (cm)	Distance from Source (cm)	Time (h)	Concentration (Bq/g)[a]	Internal Pathway[b]	No. of Individuals for 100 t[c]	No. of Individuals for 50,000 t
Tier A:	Tool Reuse	1 full disk	----[d]	----	56.4	60	2,000	1	inh, ing	1	500
Surface Reuse	Building Occupancy	4 half disks	----	----	300	100	2,000	1	inh, ing	4	2,000
Tier B:	Parking Lot	1 full cylinder	2.70	10	3,433	100	62	0.1	----	1,050	525,000
Consumer	Room/Office	4 half cylinders	7.86	0.2	300	100	2,000	1	----	144	72,000
Products	Appliance	1 half cylinder	7.86	0.1	92	100	730	1	----	343	171,500
	Automobile	4 full cylinders	7.86	0.1	150	50	668	1	----	252	126,000
	Office Furniture	1 half cylinder	7.86	0.1	103	15	2,000	1	----	554	277,000
	Home Furniture	1 half cylinder	7.86	0.1	110	15	3,650	1	----	480	240,000
	Frying Pan	1 full cylinder	7.86	0.4	15	30	180	1	ing	3,272	1,636,000
	Pavement	1 full cylinder	2.7	10	3,433	100	3.7	0.1	----	8,234,400	4,117,200,000
Tier C:	Public Building[e]	4 half cylinders	7.86	0.5	300	100	2,000	1	----	164	82,000
Specified	Bridge	2 half cylinders	7.86	1.2	1,800	100	1	1	----	8,234,400	4,117,200,000
Initial Use											
Tier D:	Shielding Block	1 half cylinder	7.86	132	105	100	2,000	1	----	----	----
Controlled	Reactor Tank	1 half cylinder	7.86	0.2	300	100	2,000	1	----	----	----
Recycle	Radwaste Container	1 half cylinder	7.86	0.27	100	100	2,000	1	----	----	----

[a] Unit is Bq/cm^2 for Tier A surface reuse scenarios.

[b] inh = inhalation; ing = ingestion.

[c] Number of individuals for consumer products includes the following mass distribution of ingots among the products: room/office 38%, appliance 8%, automobile 30%, office furniture 8%, house furniture 8%, and frying pan 8% (U.S. Bureau of Mines 1985). Parking lot and pavement scenarios use 10 tons of slag (10% of 100 t RSM).

[d] ---- means not applicable.

[e] Shielded by 15 cm of concrete.

Consumer Product Scenarios

Eight consumer product scenarios are considered in this section — parking lot, office/room, appliance, automobile, office furniture, home furniture, frying pan, and pavement scenarios. The parking lot scenario considers the use of slag in the construction of a parking lot. The slag is assumed to be diluted with concrete by a factor of 100, resulting in a radionuclide concentration of 0.1 Bq/g. Because the slag is assumed to be 10% of the total mass of steel being recycled and the dilution factor is 100, the estimated total mass of the mixture is 1,000 t. The average individual is assumed to spend 10 minutes a day in the parking lot, for an annual exposure time of 62.1 hours. For the collective dose calculation, the number of exposed individuals is estimated to be 1,050. This calculation is based on the surface area of the parking lot, the base area of an average automobile, and an average occupancy of two individuals per automobile.

The office/room scenario considers the use of sheet metal to construct the four walls of a 5 × 5 × 3 m office. If 940 kg of steel is used to construct one room, about 36 rooms could be built from recycling 100 t of RSM, (assuming that 38% is used in the construction industry). An average occupancy of four persons per room is assumed.

The appliance scenario considers the use of steel in manufacturing appliances for home use. Refrigerators, stoves, and dishwashers have been investigated for modeling. The refrigerator yields the most conservative results because of its large size. The average mass of a refrigerator is about 21 kg. If about 8% of available steel is used in the appliance industry, 343 refrigerators could be made from recycling 100 t of RSM. The number of exposed individuals applied for the collective dose calculation is 343.

The automobile scenario considers the use of steel in the body of automobiles. If about 30% of available steel is used in the transportation industry and 222 kg of steel is used in the body of an average car, about 126 automobiles could be manufactured from recycling of 100 t of RSM. An average occupancy of two persons per automobile is assumed.

The office furniture scenario considers the use of steel in office furniture. Desks, book cases, and file cabinets have been investigated for modeling this scenario. Use of the desk in the modeling yields the most conservative results because of the proximity of the desk to the office worker and the long period that the average worker could be exposed to the source. About 13 kg of steel is estimated to be used in making a desk. If 8% of available steel is used in the office furniture industry, about 554 desks could be manufactured from recycling 100 t of RSM. One person would be exposed per desk.

The home furniture scenario considers the use of steel in home furniture, such as wire bed springs. The amount of steel used in a bed is estimated to be about 15 kg. If 8% of available steel is used in the home furniture industry, 480 beds could be manufactured from recycling 100 t of RSM. One person is assumed to be exposed per bed.

The frying pan scenario considers the use of steel in frying pans for household use. The amount of steel used in a pan is 2.2 kg. If 8% of available steel is used to make frying

pans, about 3,272 pans could be produced from recycling 100 t of RSM. For the frying pan scenario, the ingestion rate was based on a corrosion rate of 0.13 mm/yr (IAEA 1988). For a frying pan with an area of 710 cm^2 and the assumed corrosion rate, approximately 1.2 g/yr of metal would be corroded. It was assumed that 50% of the corroded material would be ingested. For the collective dose calculation it is assumed that one person is exposed per pan.

The pavement scenario considers the slag to be used in highway pavement. Parameters are the same as for the parking lot, but individual exposure time differs. The average individual spends about six hours per year on the pavement, driving twice a day at a speed of 50 km/h. For the collective dose calculation, it is assumed that the traffic count is 470 cars per hour, a typical rural highway traffic frequency (Neuhauser and Kanipe 1992). Each car is assumed to have two passengers.

Other Tier B Scenarios

The use of recycled steel containing residual radioactivity for use as a surgically implanted bone prosthesis was investigated by the U.S. Nuclear Regulatory Commission in NUREG-0518 (USNRC 1980). A concentration of 17.5 ppm (0.21 Bq/g) uranium and 5 ppm (6.4×10^5 Bq/g) Tc-99 was assumed for the analysis (on the basis of a representative sampling of smelted alloys). The resulting dose was estimated to be 40 μSv per year, a factor of four higher than the assumed limit of 10 μSv/yr (IAEA 1988). These radionuclides are considered to be representative of other long-lived alpha/beta emitters investigated in this report. The use of scrap for medical implants is not considered a probable scenario, given the stringent material requirements and liability for damages associated with such practices. Hence, such a scenario should not be used to derive exemption limits.

Maximally Exposed Individual Scenarios

The following annual exposure durations were used to calculate the dose to a maximally exposed individual: 2,000 hours for the parking lot scenario (parking lot attendant), 2,000 hours for the office/room scenario, 1,000 hours for the appliance scenario, 2,000 hours for the automobile scenario (taxi driver), 180 hours for the frying pan scenario, 2,000 hours for the office furniture scenario, and 3,650 hours for the home furniture scenario.

C.2.2.3 Tier C: Recycle to Specified Initial-Use

The specified public use scenarios considered under Tier C are described in this section. The results of the analysis are presented for each scenario in Table D.30 in Appendix D.

The public building scenario considers the use of reinforcement bars in the structure of public buildings. Four walls of a 5 × 5 × 3-m room are assumed to be constructed with reinforcement bars placed 15 cm deep inside concrete. The average individual is assumed

to be located 1 m from one wall, 4 m from the opposite wall, and 1.5 m from the two adjacent walls. If 2.2 t of steel is needed to construct one room, about 41 rooms could be built from recycling 100 t of RSM. Thus, for an average occupancy of four persons per room, the number of exposed individuals for collective dose assessment is 164.

The bridge scenario considers the use of recycled steel for support beams in bridges. The bridge is assumed to be 5 m wide and 100 m long, with a beam height of 5 m. An individual is assumed to be located 1 m from one upright and 4 m from the other upright support beam of the bridge. If an average individual drives under the bridge twice per day at a speed of 50 km/h, the total exposure time is estimated to be 1 h/yr. If 100 people pass under the bridge per hour and one bridge is built from recycling of 100 t of RSM, the number of exposed individuals used for the collective dose calculation is 876,000 per year.

C.2.3 Stack Emission Scenario

The stack emission scenario (see Table D.31) considers the release of radionuclides from a smelting facility through a stack. The CAP88-PC (Version 1.0) computer code (Parks 1992) was used to perform dose assessment calculations for the maximally exposed individual. The code was developed by the USEPA to perform risk and dose assessments to evaluate compliance with 40 CFR 61.93(a). The baseline calculation is based on processing 100 t/yr of RSM with a concentration of 1 Bq/g and includes partitioning of radionuclides due to the smelting operations. On the basis of the partitioning factors listed in Table C.4, only the airborne fraction is released through the stack. The partitioning factors are based on a comprehensive review of available data in the literature, including the Safety Series 111 report (IAEA 1992), CEC Report-43 (CEC 1988), Chapuis et al. (undated), and Johnson (1993).

The maximally exposed individual is assumed to be beyond a 100-m radius from the release point. Doses are adjusted for the use of a high-efficiency particulate air filter. A decontamination factor of 2,000 (99.95% efficiency) is applied (Lee and Stoddard 1979). Other assumptions used in CAP88 calculations are shown in Table C.5 and are similar to those used by O'Donnell et al (1978).

C.2.4 Disposal Scenario

In the disposal scenario, it is assumed that 50,000 t of RSM is disposed of in an area of 11,400 m^2. The RSM is mixed with soil in a 1:1 volume concentration to form a 1-m-thick layer and is covered with 0.5 m of clean soil. For volume contamination the concentration of activity in the RSM is 1 Bq/g. For surface contamination the concentration of activity is 1 Bq/cm^2, with the average thickness of material being 10 cm. These values yield an average concentration in the RSM of 0.0125 Bq/g.

TABLE C.4 Partitioning Factors

Nuclide	Ingot	Air	Slag	Source (Bq/yr)
Ac-227	10.0	0.5	100.0	5.0E+05
Am-241	10.0	0.5	100.0	5.0E+05
Pu-239	10.0	0.5	100.0	5.0E+05
U-238	10.0	0.5	100.0	5.0E+05
Sr-90	10.0	10.0	100.0	1.0E+07
Tc-99	10.0	100.0	10.0	1.0E+08
Co-60	100.0	0.5	1.0	5.0E+05
Cs-137	0.1	100.0	100.0	1.0E+08
Zn-65	1.0	100.0	1.0	1.0E+08
H-3	0.0	100.0	0.0	1.0E+08
C-14	0.0	100.0	0.0	1.0E+08
I-129	0.0	100.0	0.0	1.0E+08
Rn-220	0.0	100.0	0.0	1.0E+08
Rn-222	0.0	100.0	0.0	1.0E+08
Th-228	10.0	0.5	100.0	1.0E+08
Th-232	10.0	0.5	100.0	1.0E+08
Ra-224	10.0	0.5	100.0	1.0E+08
Ra-226	10.0	0.5	100.0	1.0E+08

TABLE C.5 Assumptions Used in CAP88 Calculations

Parameter	Value
Stack Height	43 m
Exit Velocity	3 m/s
Stack Diameter	6 m
Population Data File	Argonne.pop
Wind Data File	ORD0452.wnd
Food Consumption	Urban

The two different contamination types affect the assumptions about the availability of the radionuclides to leach from the contaminated zone. For surface contamination, it is assumed that the radionuclides are bound to the RSM until released through erosion processes. A simplified erosion process was adopted by assuming linear erosion over 100 years. This erosion process cannot be directly simulated with the RESRAD code. The methodology section details how the doses were estimated.

For dose calculations, two maximally exposed individuals were defined — a worker at the site after disposal and a resident living on the disposal site. Dose estimates are given in Tables D.32 and D.33. The site is released to the public 30 years after the disposal of the RSM. The worker is only exposed to external ground shine. The resident is subject to the environmental pathways (including radon inhalation). The disposal scenarios can be classified according to three parameters: site type (managed or unrestricted), exposed individual type (worker or resident), and RSM contamination type (surface or volume contamination).

C.3 DERIVATION OF RELEASE LEVELS

The activity level (L, in Bq/cm^2 or Bq/g) that is protective of workers or the public can be derived for a particular radionuclide from unit dose factors according to the following equation:

$$L = \frac{D_0}{D}, \tag{C.12}$$

where D_0 (in μSv/yr) is the dose constraint to an individual (assumed to be 10 μSv/yr for release level derivation) for the release, and D (in μSv/yr per Bq/cm^2 or μSv/yr per Bq/g) is the worker or public dose per unit activity concentration (e.g., 1 Bq/cm^2 or 1 Bq/g). The cumulative population dose (DP) resulting from radioactive scrap metal release is obtained by:

$$DP_k = N_k \times D_i^k \times F_i \times T \tag{C.13}$$

where N_k is the number of exposed individuals for population subgroup k; D_i^k is the first annual dose received by population subgroup k based on a unit nuclide concentration (person-Sv/yr per Bq/g or per Bq/cm^2); F and T are factors pertaining to the accumulation of dose over time (which are discussed further below); and i represents the radionuclide contained in the metal.

The factors F and T in Equation C.2 represent the nuclide average decay factor and the time multiplier of population dose, respectively, over the long-term use of radioactive scrap metal products. Both factors pertain to the useful life of the products, after which time portions of the radioactive scrap metal will be recycled in a continual process, although the dose contribution from the same radioactive scrap metal will diminish over time. These two factors only apply in the Tier B and C analyses. If the product life is T_r years and the

fraction returned for future recycle is f_r, the average decay factor of each nuclide over the product life is:

$$F_i = \frac{1 - EXP\ (-\lambda_i \times T_r)}{\lambda_i\ T_r}\ , \qquad \text{(C.14)}$$

and the time multiplier can be shown to be:

$$T = \frac{T_r}{(1 - f_r)}\ , \qquad \text{(C.15)}$$

where λ_i is the nuclide decay constant. For Tier B the product life T_r is assumed to be 10 years for consumer products (including slag used for public pavement), and for Tier C it is assumed to be 30 years for public structures (e.g., buildings or bridges). According to IAEA Safety Series No. 111-P-1.1 (IAEA 1992), f_r is about 0.2, (i.e., about 20% of the scrap metal gets recycled every year). Recent rates in the U.S.A. are about 0.25 per year. Repeated recycling is not assumed for slag used in pavement.

C.4 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to identify major areas of uncertainty and to guide the assumptions used as a basis for defining cases for dose estimation. The case definitions are presented for conservative, modified-conservative, and protected cases.

C.4.1 Case Assumptions

On the basis of the sensitivity analysis findings, three analytical cases were developed to apply to volumetric and surface contamination, which are defined below. Results for the modified-conservative case are shown in Chapter 5.

- ***Volumetric Contamination***

  - *Conservative Case* — Uses a partitioning factor of 1 for all scenarios and a dilution factor of 1. This case is similar to the Safety Series No. 111-P-1.1 (IAEA 1992) baseline case except that updated information has been used for some parameters.

  - *Modified-Conservative Case* — Uses empirical data for partitioning factors (Table B.3) and a dilution factor of 0.1.

  - *Protected Case* — Uses empirical data for partitioning factors, a dilution factor of 0.1, and a protection factor of 0.01 (affecting inhalation and ingestion pathways). The protection factor assumes that workers wear gloves and coveralls and use respiratory

protection. Shielding could provide virtually complete protection from external exposure, but that factor is not modeled because processing is assumed to occur in a commercial smelter.

- ***Surface Contamination***

  - *Conservative Case* — Surface transfer factor is 1.

  - *Modified-Conservative Case* — Surface transfer factor is 0.01, which is similar to the IAEA Safety Series No. 111-P-1.1 (IAEA 1992) assumption regarding transfer of contamination from the surface to the room air.

  - *Protected Case* — Surface transfer factor is assumed to be 1×10^{-4} based on the capability of decontamination techniques for removal of nonfixed contamination.

These cases were used to establish the range of doses and derived activity levels generated by modeling assumptions that range from conservative to realistic. From this range, the modified-conservative case was selected for presentation of the study findings. This case has a strong empirical basis, and it substantially reduces the level of conservatism in derived activity levels relative to previous studies.

Conservative assumptions are typically employed in various dose assessment steps because of uncertainty regarding appropriate parameter values. Sensitivity of dose estimates to the parameter assumptions and the ramifications for release standards are discussed below. The calculational framework within which parameter sensitivity was analyzed is presented in Figure C.1 for volumetric contamination and Figure C.2 for surface contamination. These diagrams show the major computational steps and the parameter values employed in the modified-conservative case. The parameters analyzed and the dose estimates affected by each parameter are indicated in Table C.6. The parameters vary in importance from those, such as the dilution and partitioning factors, that substantially affect multiple scenarios to those that only affect one exposure pathway for one scenario. Baseline values and an estimate of the level of conservatism represented by that value are indicated for each parameter. The relevant parameters are discussed below in relation to each category of dose calculation (e.g. Tier B individual public dose), and the availability and effectiveness of protective measures are indicated.

C.4.2 Doses to Workers

Worker scenarios for each step in the recycle process are adapted from Safety Series No. 111-P-1.1 (IAEA 1992). For Tier B-1, worker scenarios are included for scrap delivery, scrap processing, smelting, product fabrication, and distribution; just fabrication and distribution are included for Tier B-2. Exposure pathways for workers include inhalation,

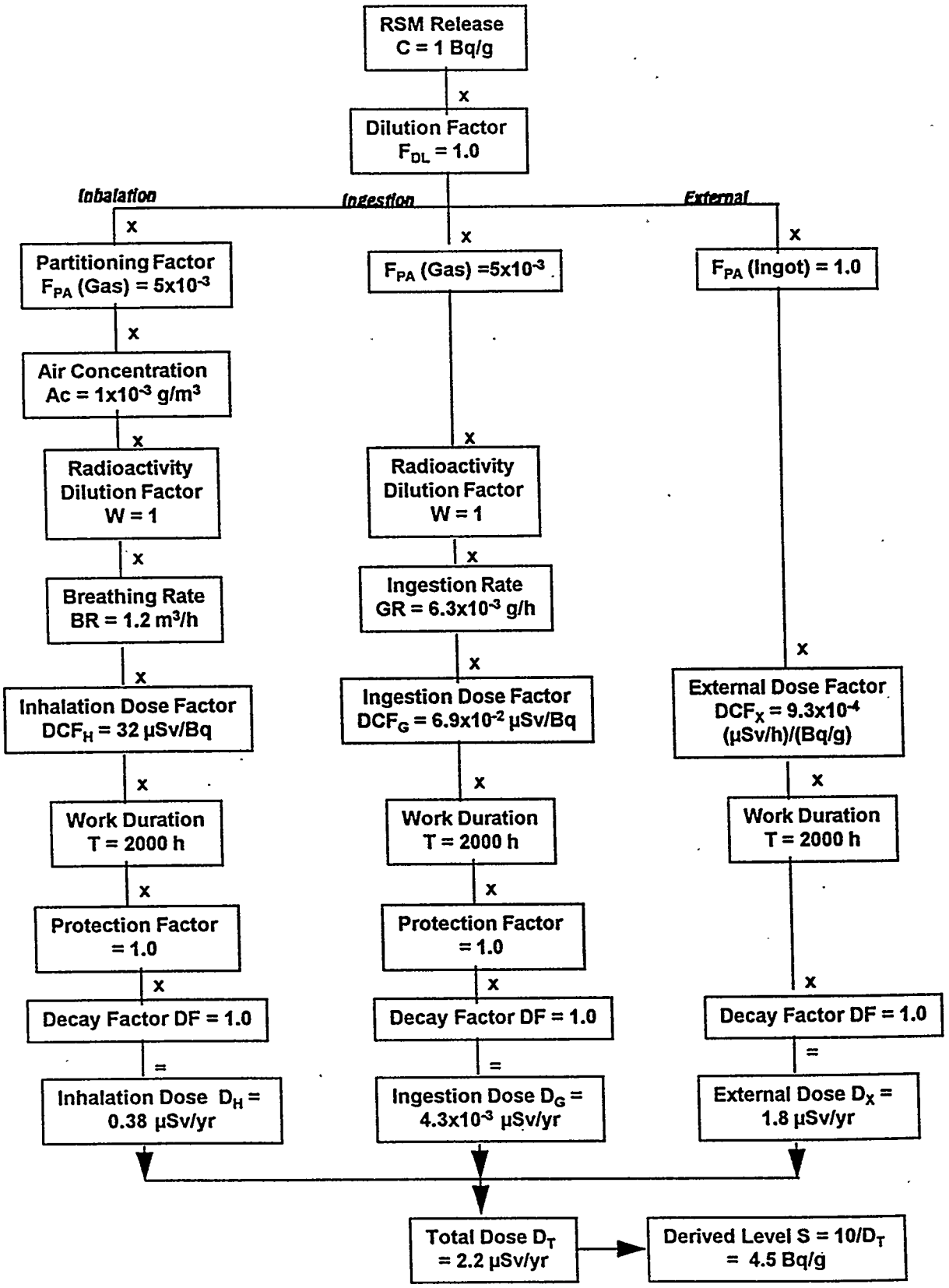


FIGURE C.1 Computational Process for Volumetric Release Levels (U-238, Slag Worker Scenario)

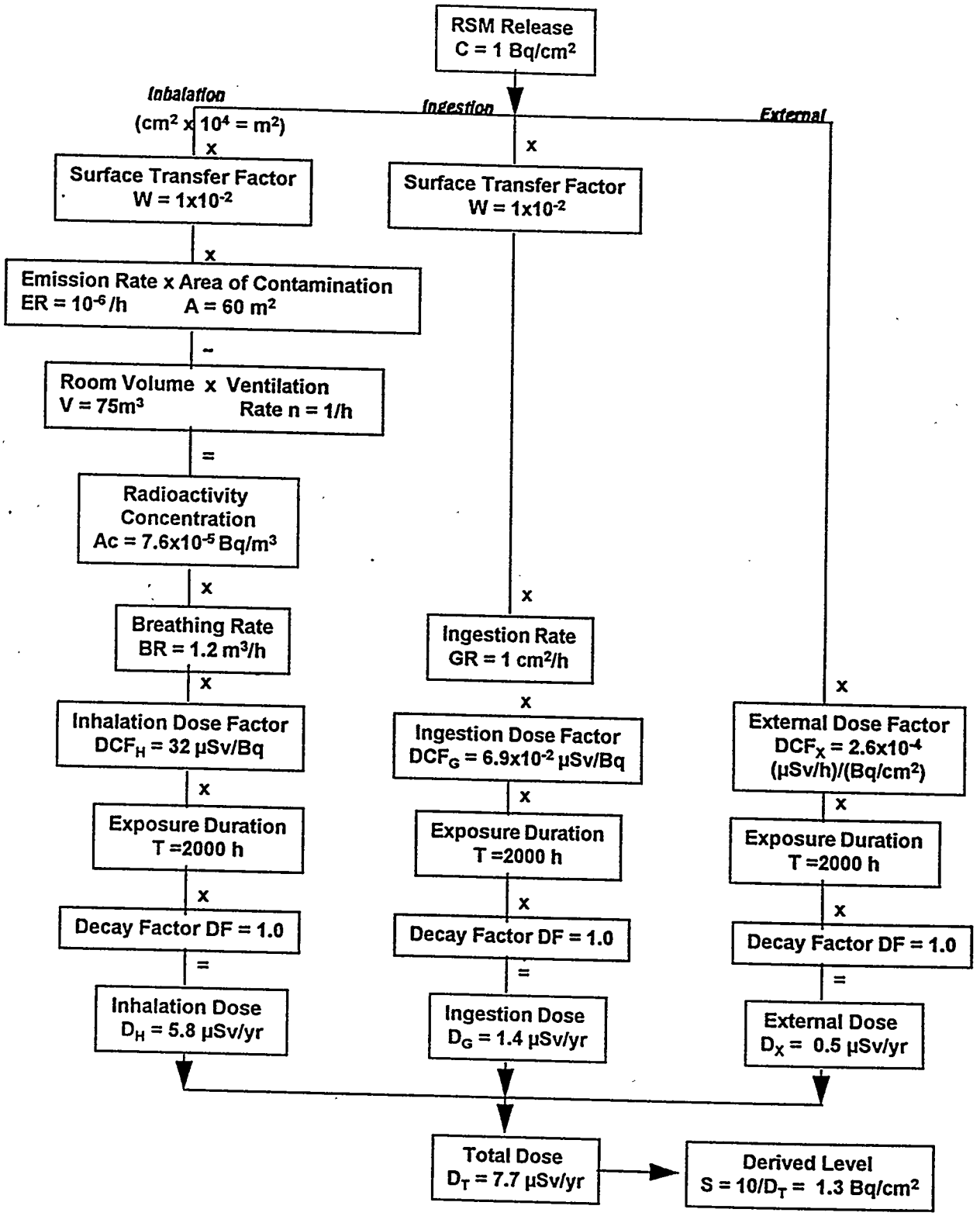


FIGURE C.2 Computational Process for Surface Release Levels (U-238, Room Occupancy Scenario)

TABLE C.6 Key Parameters in Dose Estimation for Radioactive Scrap Metal Reuse or Recycling

Parameter	Tier Affected	Dose Affected	Group Affected	Baseline Value	Range of Conservatism
Dilution factor	B-1	Individual Population	Worker Public	1.0	$10 - 10^2$
Partitioning factor	B-1	Individual Population	Worker Public	1.0	$1 - 10^2$ (depending on the nuclide)
Air concentration	B-1	Individual Population	Worker	10^{-3} g/m^3	10+
Ingestion rate	B-1	Individual Population	Worker	6.25×10^{-3} g/h	$10 - 10^3$
Surface transfer factor	A-1	Individual	Public	0.01	10^2
Emission rate	A-1	Individual	Public	10^{-6}/h	10+
Air exchange	A-1	Individual	Public	1/h	-
Surface ingestion rate	A-1	Individual	Public	10^{-4} m^2/h	$10 - 10^2$
Radon emanation and plate out	A-1	Individual	Public	1.0	10+
Steel corrosion rate	B	Individual Population	Public	0.13 mm/yr	10+

ingestion, and external exposures from metal preparation, smelting, and processing activities. Annual doses for workers were estimated on the basis of 2,000 hours of exposure, although fewer hours might be required for some worker categories to process 50,000 t of RSM without dilution.

C.4.2.1 Dilution Factor

Assuming no dilution of RSM in commercial smelters is unrealistic because the total RSM inventory is only a fraction of the entire scrap metal stock and the RSM is likely to be recycled over many years. In practice, the dilution factor would vary substantially with parameters such as RSM quantities in each region, furnace technology, scrap throughput, and mill capacity. The potential range of dilution proportions is considered for an annual throughput of 50,000 t per foundry (i.e., three foundries processing the projected annual RSM inventory flow of about 150,000 t from years 2010 to 2043 in North America (see Section 3). Dilution proportions are derived in Table C.7 assuming that the RSM is mixed with other scrap inputs in processing. The proportion of RSM in products if all RSM goes to just three

TABLE C.7 Steel Mill Technology and Capacity Relative to Potential 50,000 t Annual Radioactive Scrap Metal Throughput in North America

	Basic Oxygen Furnace			Electric Arc Furnace		
Parameter	Low	Average	High	Low	Average	High
Mill capacity (10^6 t/yr)	0.9	2.4	4.5	0.4	0.8	2.7
Radioactive scrap metal dilution rate[a]	0.19	0.07	0.04	0.13	0.06	0.02

[a] Projected radioactive scrap metal quantity available annually, divided by furnace capacity (based on Table 4.1).

commercial smelters ranges from as high as 0.19 in a low-capacity basic oxygen furnace to a low of 0.02 in a high-capacity electric arc furnace. The average dilution is more than tenfold, and the doses would be reduced accordingly because all dose estimates are linearly proportional to the dilution factor. This dose reduction from dilution applies to commercial smelter worker doses and public doses from products after commercial smelting.

C.4.2.2 Partitioning Factors

The nuclide partitioning factors reflect the fraction of the original radionuclide activity in the various end products of the steel smelting processes (ingots, slag) and the work environment (dust, offgas). These factors, which affect all pathways and all scenarios, are each assumed to have a value of 1.0 in the conservative case estimates (i.e., the ingot, slag, and offgas/dust each have the same activity as the original scrap metal) (IAEA 1992). This conservative approach is applied because of the large variation in partitioning rates, depending on melt conditions. Some typical radionuclide partitioning values have been suggested by IAEA (1992) and by Chapuis et al. (undated]. Reviews by Hertzler et al. (1993) and Otis (1995) indicate a range of partitioning factors among nuclide such that nearly 100% of the original activity may remain in the ingot (e.g., Co-60) or nearly 100% may be incorporated in slag (e.g., Am-241). Because of uncertainty, a high estimate is used for some nuclides (e.g., 100% in slag for Cs-137), even though most of the mass would likely end up in the offgas or baghouse dust. Partitioning rates vary with furnace type, melt temperature, flux chemistry, and other factors. The range of values for representative nuclide is summarized in Table C.8. Use of such data, where available, reduces dose estimates for metal product scenarios by two orders of magnitude in some cases. However, it should be noted that because partitioning factors affect each pathway, the effect on total dose of variation in partitioning factors is highly dependent on scenario definitions. This effect also applies to commercial smelter worker doses and public doses from products after commercial smelting.

TABLE C.8 Steel Melt Partitioning Factors of Representative Radionuclides[a]

Radio-nuclide	Ingot		Slag		Offgas	
	Assumed Value	Range	Assumed Value	Range	Assumed Value	Range
H-3	0	0	0	0	1	1
Co-60	1	0.2 - 1	0.01	0 - 0.75	0.005	0.005 - 0.1
Zn-65	0.01	0 - 1	0.01	0 - 0.13	1	0.01 - 1
Sr-90	0.1	0.1 - 1	1	0.8 - 1	0.1	0.1
Tc-99	0.1	0.1	0.1	0.1	1	1
Cs-137	0.001	0 - 0.001	1	0.02 - 1	1	0.03 - 1
Pu-239	0.1	0.01 - 0.1	1	1	0.005	0 - 0.01

[a] Alpha emitters such as Ac-227, Am-241, and U-238 are assumed to have the same partitioning factors as Pu-239.

Sources: Assumed values are from Chapuis et al. (undated) and IAEA (1992); ranges are from Hertzler et al. (1993), Johnson (1993), and Sanford Cohen and Associates (1995).

C.4.2.3 Air Concentration

The air concentration of a radionuclide in the work environment directly affects inhalation dose in a manner similar to the partitioning factor. The dust loading factor of 10^{-3} g/m^3 (IAEA 1992) assumed for all three cases is at the high end of the range for uncontrolled work environments. Particulate air concentrations generally range from 5×10^{-5} (residential scenario in NUREG\CR-5512 [USNRC 1992]) to 1.8×10^{-3} g/m^3 (for coal mining [Oztunali 1981]). With effective ventilation, dust loading can be substantially decreased (proportionally to the ventilation rate), which would reduce potential doses to workers. Reducing the air concentration by a factor of 10 (i.e., to 10^{-4} g/m^3) would reduce the overall dose by about a factor of 10 for alpha emitters and a factor of 2 for beta emitters, but would have almost no impact for gamma emitters.

C.4.2.4 Ingestion Rate

For ingestion doses, the key parameters are the ingestion rate and the partitioning factors. An ingestion rate of 6.25×10^{-2} g/h (USEPA 1991), derived from the dirt ingestion rate for children, is applied for all cases. This value is recommended by the U.S. Environmental Protection Agency (EPA) for adults in an occupational setting but is very conservative because workers are generally well trained to avoid ingesting dust and are likely to wear gloves. With such protective measures, dust ingestion can be substantially curtailed or even eliminated. However, since the worker doses (see Figure C.3a) are not dominated by the ingestion pathway, the total dose is not especially sensitive to the ingestion rate.

C.4.2.5 Factors Related to External Dose

Factors controlling external exposure include the distance of workers from materials, effectiveness of shielding, and work duration. No shielding for workers was assumed because personal shielding may disrupt the work procedure.

C.4.2.6 Protection Factor

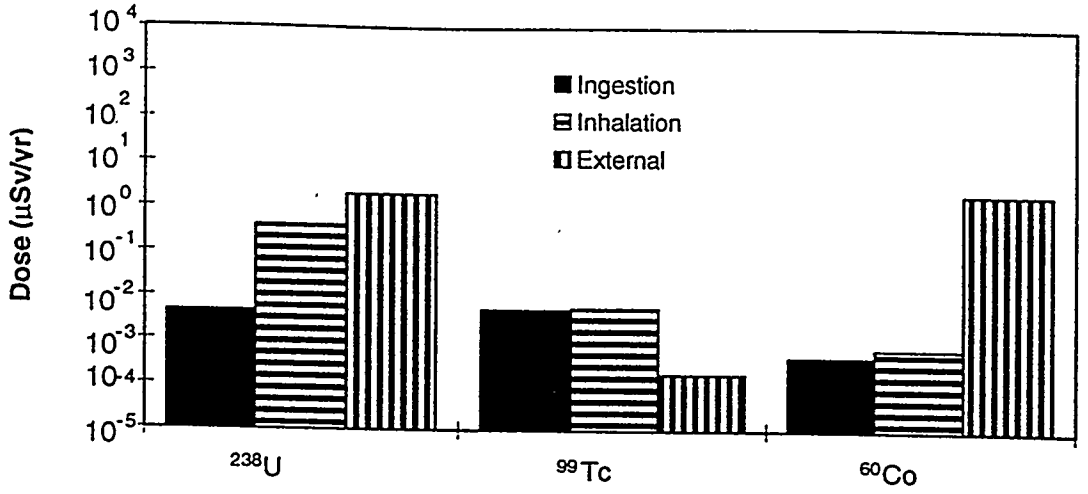
Protective equipment, such as masks, protective suits, and gloves, is ordinarily required for workplace hazards. For radioactive scrap metal smelting in a commercial foundry or mill, protection against radiation would not be required because the smelter is not expected to be licensed as a nuclear facility. If desired, however, respirators (usually available with an efficiency range from 99 to 99.9%) could be employed, thereby reducing the inhalation dose by a factor of 100 to 1,000. A protection factor of 0.01 is assumed in the protected case. Sensitivity of the total dose to inhalation protection is similar to that for the partitioning factor. Wearing gloves would virtually eliminate ingestion but would not significantly reduce total doses. The major impact would be on beta emitters, but the dose reduction would be no more than 50%. Unfortunately, no effective means exist to protect against external gamma radiation except, perhaps, remote control.

C.4.2.7 Sensitivity of Key Parameters

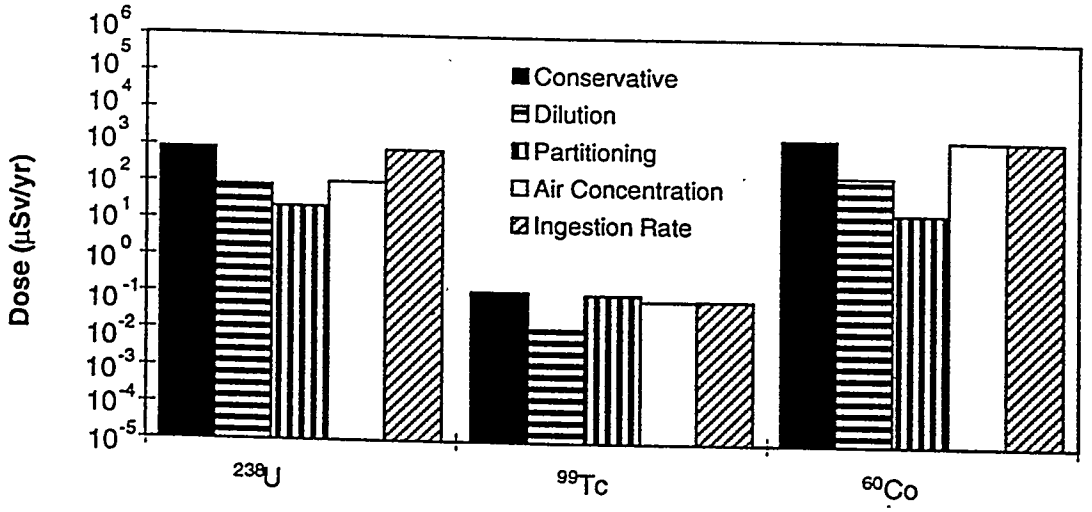
Figure C.3 illustrates parameter relationships to dose estimates for the Tier B-1 slag worker scenario. The relative magnitude of dose pathway contributions to total dose is shown in Figure C.3a, and the effect on dose estimates of varying each of the key parameters separately by 10% is shown in Figure C.3b. Dose estimates are clearly most sensitive to partitioning and dilution factors. The effect on dose estimates of dilution and partitioning information, separately and combined, is shown in Figure C.3c.

Figure C.3b shows worker dose sensitivity to partitioning factors for the most constraining worker scenario, slag workers. The conservative case doses are dominated by the inhalation pathway for alpha emitters (above 90% of total effective dose) and for beta emitters (slightly above 50%) and by the external exposure pathway for gamma emitters (nearly 100%). Application of partitioning factors reduces total dose estimates considerably. Relative to conservative case dose estimates, partitioning reduces doses for alpha emitters by up to 99%, up to 70% for beta emitters; and up to 99% for some gamma emitters. Dose reduction for alpha emitters is most substantial because these elements tend to concentrate in slag, thus reducing the inhalation dose from dust and offgas.

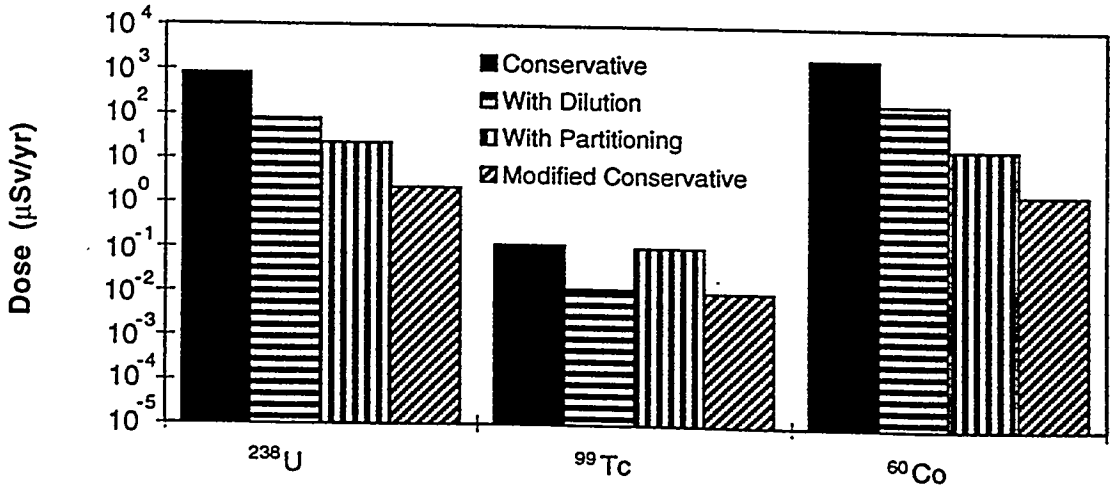
Although partitioning factor data are available for offgas and dust combined, partitioning rates between offgas and dust in the work area are unknown. Additional conservatism is introduced by assuming the same partitioning factors for the dust as for the offgas, although it is likely that dust would have lower radioactivity concentrations.



(a) Relative Contribution of Dose Pathways to Total Dose under Modified-Conservative Case Assumptions



(b) Slag Worker Sensitivity Analysis (partitioning factors included and other factors multiplied by 10%)



(c) Effects on Dose Estimates of Incoporating Dilution and Partitioning Information

FIGURE C.3 Parameter Relationships to Worker Dose Estimates for the Slag Worker Scenario

C.4.2.8 Level of Conservatism

From this analysis, the baseline level of conservatism in dose estimates for alpha emitters (inhalation dominant) ranges from a factor of 10 to 10^4. With dilution, partitioning, and protection factors, the conservative case dose estimates for alpha emitters are reduced by a total factor of 10^3 to 10^7. For ingestion-dominant nuclides (some beta emitters), dose estimates are reduced by a factor of 10 to 100 by use of realistic dilution and partitioning factors. In addition, with proper training and clothing, worker ingestion doses could potentially be eliminated. For gamma emitters (external exposure), the baseline conservatism level is about 10 to 10^4, depending on the nuclide. External doses can be controlled with remote operations, as can all worker doses from other pathways and other toxic exposures associated with normal smelting operations. Worker doses could also be decreased by other factors, such as lower radioactive scrap metal throughput, worker rotation, and as low as reasonably achievable (ALARA) practices.

C.4.3 Doses to Public

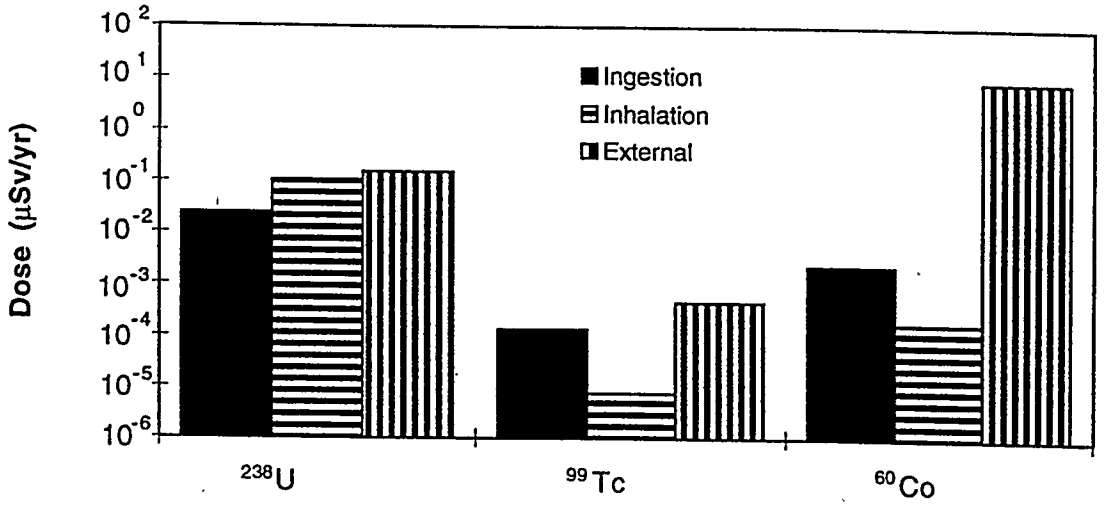
The public exposure scenarios cover the three reuse/recycle tiers (Tiers A, B, and C) of potential product end uses. These scenarios are discussed in Sections C.4.3.1, C.4.3.2, and C.4.3.3.

C.4.3.1 Public Reuse Scenarios — Tier A

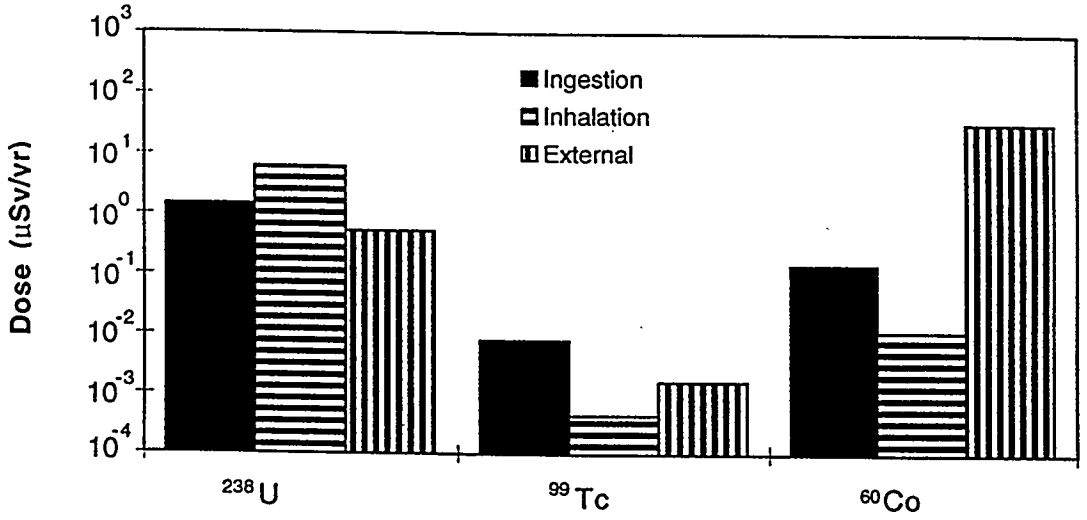
For Tier A-1, a room occupancy scenario (USNRC 1992) was analyzed for reuse of a building or of large equipment with surface contamination. The conservative case assumes uniform contamination of the four walls of a 5 × 5 × 3 m room. An additional scenario was developed for reuse of small tools or equipment, with an area of 1 m^2 assumed. Doses from surface contamination could occur through inhalation (including radon and its progeny), ingestion, and external pathways.

The modified-conservative dose components for the tool and room reuse scenarios of Tier A-1 are shown in Figures C.4a and C.4b, respectively. Doses from alpha emitters are dominated (more than 50%) by inhalation dose; beta emitters by ingestion; gamma emitters by the external pathway; and radon parents by inhalation of radon. Several key factors affecting total dose are discussed below. The effect on the dose estimate of separately varying each of the key factors by 10% is shown in Figure C.4c. The importance of these factors differs depending on the dominant exposure pathway.

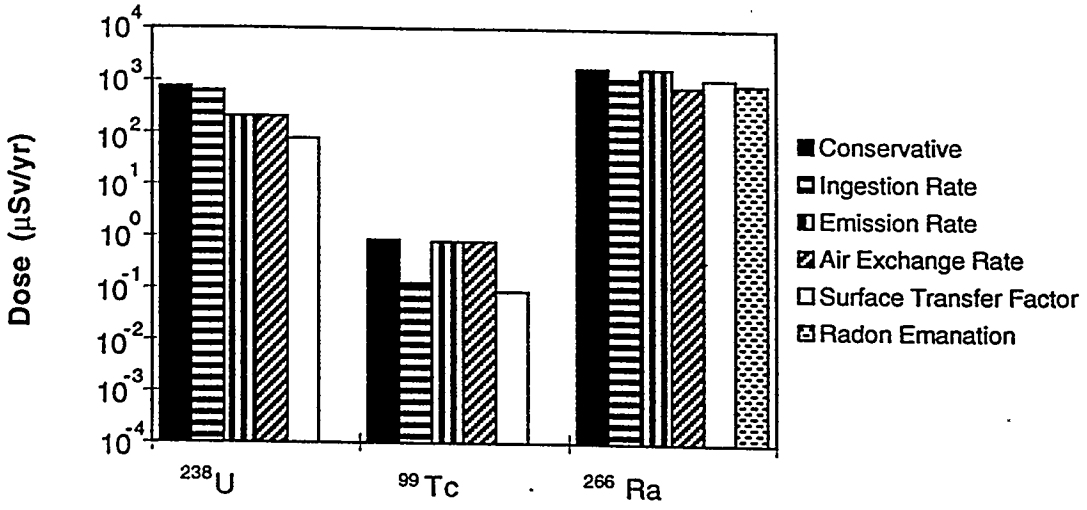
Tier A-2 is for reuse of a tool or equipment with volumetric contamination and assumes an object 1 m in height with radius of 64 cm and an activity concentration of 1 Bq/g. Only external exposure is included in the dose calculation.



(a) Tool Use



(b) Room Occupancy



(c) Room Occupancy - Sensitivity Analysis (factors multiplied by 10%)

FIGURE C.4 Relative Contribution of Dose Pathways for Tier A-1 Reuse Scenarios under Modified-Conservative Case Assumptions

Surface Transfer Factor

To account for dilution of radioactive particles with other dust particles on material surfaces, a "surface transfer factor" (assigned a value of 0.01) was used in Safety Series No. 111-P-1.1 (IAEA 1992) and applied to both inhalation and ingestion doses. This is not included in conservative case doses because it is omitted from NUREG/CR-5512 (USNRC 1992); it is included in the modified-conservative case.

Emission Rate

The radionuclide emission rate used for RESRAD-BUILD (10^{-6}/h) is suggested by Healy (1971) for room occupancy. Because the mobility of surface contaminants is likely to be curtailed through rigorous decontamination processes and surface painting before release for reuse, the level of conservatism in this parameter could be substantial. The inhalation dose estimate is directly proportional to the emission rate. For alpha emitters, reduction of the emission rate by a factor of 10 would reduce total doses by about a factor of 5. The reduction is less for nuclides whose doses are not dominated by the inhalation pathway.

Air Exchange Rate

A typical room air exchange rate of 1/h was assumed. Forced air circulation could reduce the contaminant concentration in air and thereby reduce inhalation doses, especially the radon dose. Although forced ventilation is an effective means of reducing inhalation doses, such mitigation cannot be ensured once the building is released for public use. This approach results in inhalation doses comparable to the use of the 10^{-6}/m surface resuspension factor suggested in NUREG/CR-5512 (USNRC 1992) or Safety Series No. 111-P-1.1 (IAEA 1992).

Surface Ingestion Rate

The surface ingestion rate of 1 cm^2/h (IAEA 1992; USNRC 1992) is based on nonfixed surface contamination, and assumes that during each hour of exposure all the activity associated with a given cm^2 would be ingested. This value is extremely high considering the thorough decontamination process that would be likely before radioactive scrap metal release. Further, the scenario assumes transfer of contaminants from surface to hand to ingested foods, which is not a likely event in the general office setting to which the room occupancy scenario pertains. Thus, the level of conservatism in the ingestion dose is at least a factor of 100. This primarily affects dose estimates for beta emitters (such as Sr-90) for which ingestion contributes 90% or more of total dose.

Factors for External Dose

Dose is reduced by a factor of 2 to 4 if only one wall is contaminated. Also, room size and receptor location (assumed at 1 m from a wall) would affect the dose estimate. Such general factors would change the results by a factor of 2 to 3. Shielding could further reduce dose estimates. The level of conservatism in resulting dose estimates is a factor of about 5 to 10.

Factors Related to Radon

Radon is assumed to be immediately released (i.e., an emanation factor or release fraction of 1) by the decay of its parent nuclide. However, radon may be actually attached to particles on the surface, allowing only a fraction of the radon present to be freely released. Plate out (e.g., on furniture or drapes) of particulates may also reduce the air concentration of radon progeny. In addition, room ventilation is effective in reducing radon concentration. Radon emanation factors generally vary from 0.1 to 0.3 in soil (Yu et al. 1993a), but no data were found for surface contamination of materials. Use of a realistic value reduces all radon dose estimates by about factor of 10 or more and the total doses for Ra-226 and Th-230 accordingly.

Protection Factor

Following decontamination, sealant or paint could be applied over the surface of objects. By this means, doses from ingestion and inhalation can be largely eliminated (total doses reduced by a factor of 10^3 or more for alpha and beta emitters and for radon parents). This could leave gamma emitters as the constraining nuclides for Tier A-1. However, although effective in the short run, the long-term effectiveness of painting is questionable because the protection could be degraded over time.

Level of Conservatism

Overall, the level of conservatism in conservative case doses from Tier A-1 metal reuse is estimated to be about a factor of 10 to 1,000 for alpha and beta emitters and a factor of 1 to 10 for gamma emitters. For ingestion-dominant nuclides, the level is highly uncertain. For radon, assuming a normal room ventilation rate, the level of conservatism is a factor of 10 or more.

C.4.3.2 Consumer Product and Prescribed Initial-Use Scenarios — Tiers B and C

Scenarios for the use of consumer products predominantly result in external exposures, except in the case of frying pans for which ingestion is the primary pathway for some nuclides. For Tier B, unrestricted metal recycling, basic scenarios and assumptions

follow Safety Series No. 111-P-1.1 (IAEA 1992). Tier B-1 assumes commercial remelting, with resulting radionuclide partitioning and dilution, while B-2 assumes fabrication into products without remelting. Tier B-1 also includes use of slag in pavement. External exposure is the only identifiable pathway to the public for the Tier C-specified initial use scenarios, which include use of structural steel and reinforcing bars in bridges and public buildings.

Key parameters for Tier B-1 include the ingot partitioning factor and the dilution factor. Figure C.5 illustrates the sensitivity of dose to the dilution and partitioning factors for the constraining taxi driver scenario for Tier B-1. The modified-conservative case includes both partitioning and dilution factors.

Dilution Factor

The metal dilution factor is linearly proportional to public doses, and including this factor reduces doses in all Tier B-1 scenarios by a factor of 10 or more.

Partitioning Factor

As discussed for worker scenarios, the partitioning factor is also a key parameter for consumer products made from remelted metal or from slag (Tier B-1). Except for Co-60, dose estimates generally decrease by more than a factor of 10 because of the effect of the partitioning factor, and dose reduction from the conservative case by a factor up to 100 is possible. Because Co-60 has a partitioning factor of 1 for ingots, no dose reduction would occur for public end uses from partitioning.

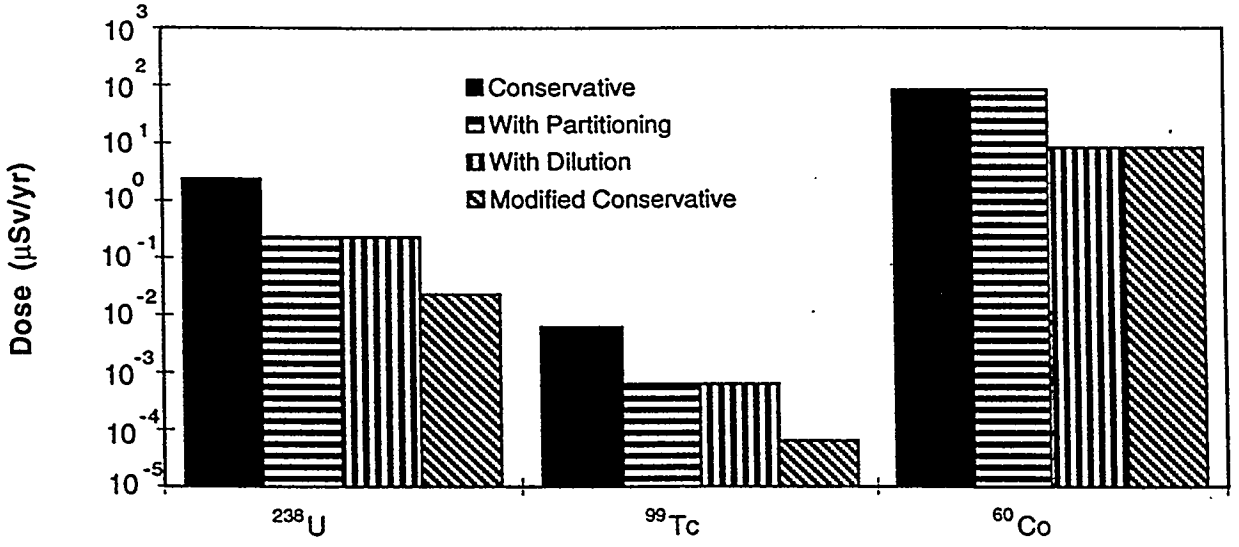


FIGURE C.5 Effects on Dose Estimates of Incorporating Dilution and Partitioning Information under the Tier B-1 Taxi Driver Scenario

Sensitivity of Tier B-1 dose estimates to partitioning is similar for all scenarios except the frying pan scenario because all other exposures are external. For the frying pan scenario, ingestion dose is the major component of total dose for most of the alpha and beta emitters.

Steel Corrosion Rate

For the frying pan scenario, a corrosion rate of 0.13 mm/yr was assumed (derived from the natural iron corrosion rate of 1.3 mm/yr). The corrosion rate only affects dose via the ingestion pathway, which is significant (more than 70% of total dose) for nuclides such as Ac-227, Am-241, Pu-239, and Sr-90. The level of conservatism in the corrosion rate is a factor of 10 or more because a corroded utensil would probably not be used for cooking and, if used, it is unlikely that all corrosion products would be retained in prepared foods.

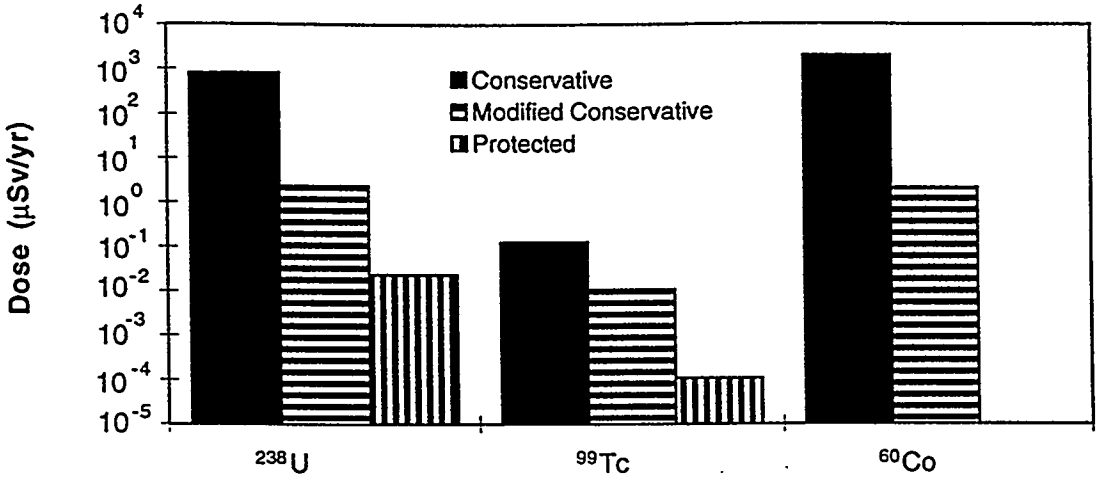
Level of Conservatism

Summing over the dilution, partitioning, and corrosion factors, the combined level of conservatism in public dose estimates is from a factor of 10 to 10^3, depending on the radionuclide considered.

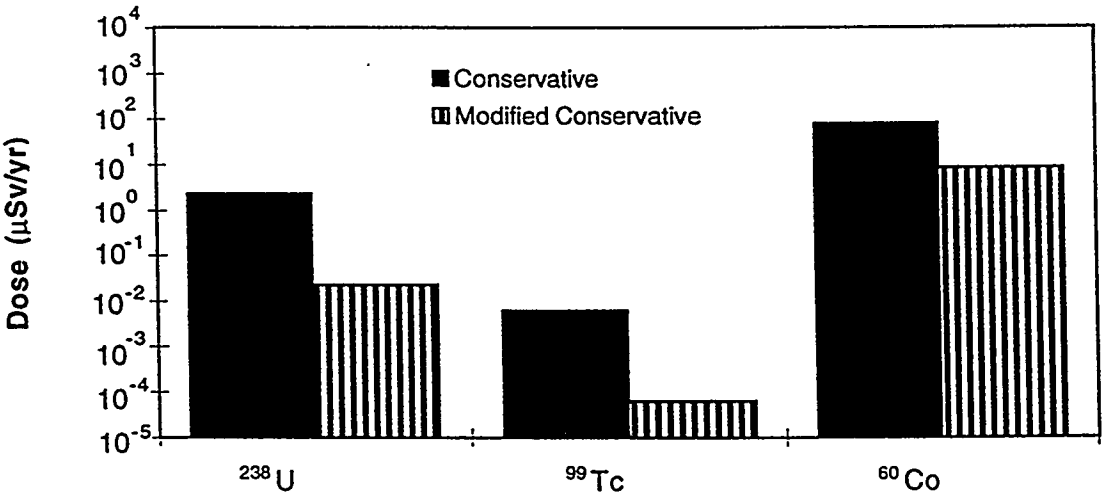
C.4.4 Effect of Case Assumptions on Dose Estimates

The effect of the case assumptions on dose estimates is illustrated in Figures C.6 and C.7. Figure C.6 shows the dose estimates for the various cases for the Tier B-1 slag worker and taxi driver scenarios. In both scenarios, the employment of dilution and nuclide partitioning information reduces dose estimates and increases activity levels by at least one order of magnitude for all categories of nuclides. For nuclides that primarily partition to slag (e.g., U-238), derived levels increase by up to two orders of magnitude relative to the conservative case. For nuclides that primarily partition to offgas (e.g., Tc-99), respiratory protection of workers (Figure C.6a) reduces doses and increases levels by up to two orders of magnitude relative to the modified-conservative case. In the case of Co-60 and other nuclides that primarily partition to the ingot, derived levels for scenarios involving metal exposure are increased only by diluting the radioactive scrap metal in the melt batch or reducing exposure time.

Figure C.7 presents a similar dose estimate comparison for Tier A-1 scenarios. For the surface contaminated tool reuse scenario shown in Figure C.7a, use of a realistic assumption for the rate of contamination transfer from the tool surface to room air reduces dose estimates by more than one order of magnitude relative to the conservative case for nuclides with dominant inhalation and ingestion pathways (e.g., U-238 and Tc-99). In the room occupancy scenario, this effect is magnified by the spatial geometry. Assuming greater decontamination effectiveness (protected case) also has greater impact on doses in the room

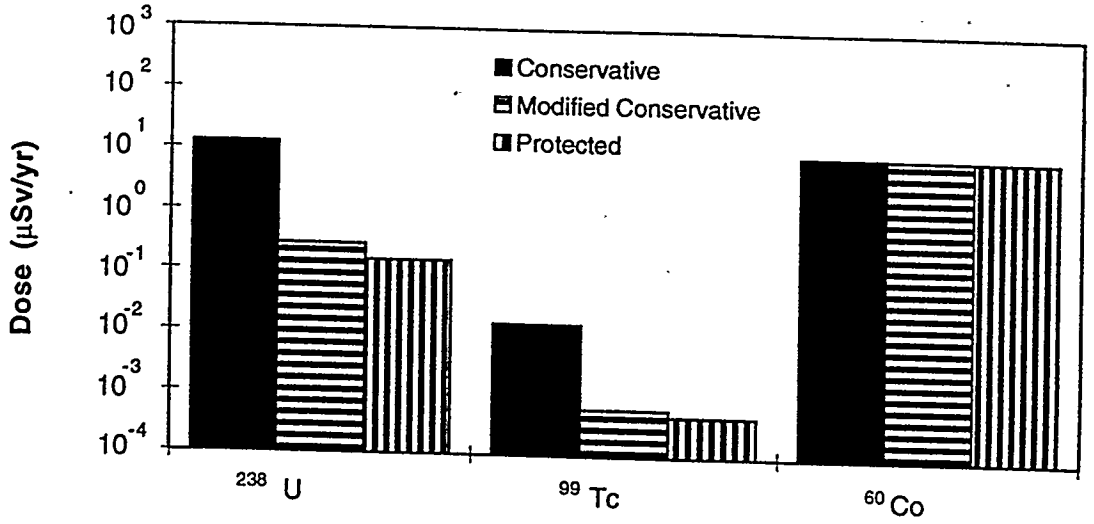


(a) Slag Worker Scenario

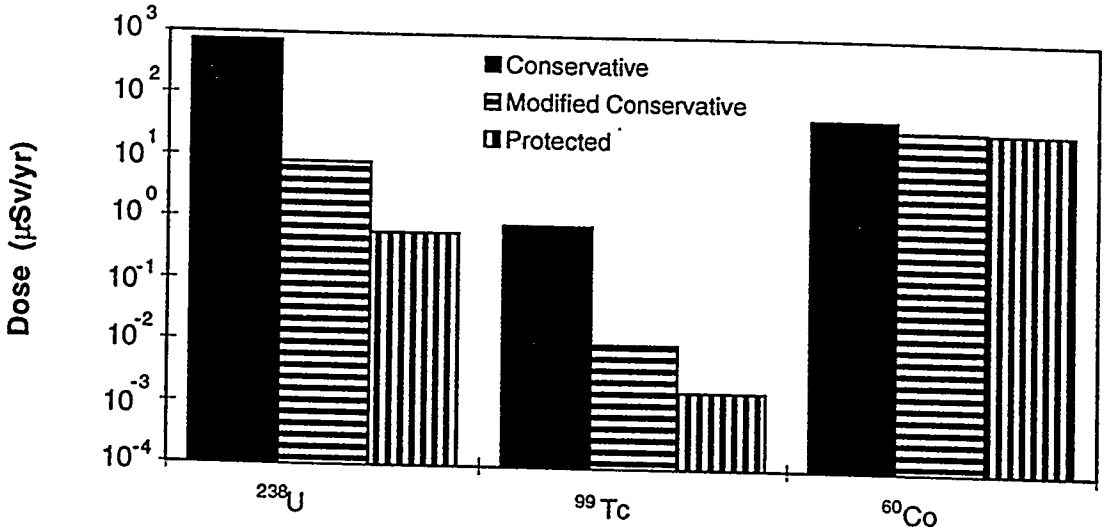


(b) Taxi Driver Scenario

FIGURE C.6 Dose Estimate Variation for Tier B-1 under Parameter Assumptions for Each Case



(a) Tool Reuse Scenario



(b) Room Occupancy Scenario

FIGURE C.7 Dose Estimate Variation for Tier A-1 under Parameter Assumptions for Each Case

scenario. Dose estimates and derived levels for nuclides where external exposure dominates dose (e.g., Co-60) are largely unaffected by these assumptions.

C.5 PROBABILISTIC ANALYSIS

A simulated probabilistic analysis of dose estimates was conducted to examine the effect of this approach for setting release standards. Figure C.8 shows the cumulative probability of a given individual dose lying within the range of estimated doses, from the minimum dose to the maximum. Both a linear and a normal distribution of dose estimates are shown to indicate that the dose level, and therefore the derived release level, that protects 90% of the exposed population can differ substantially substantially (X_{90}^{N} versus X_{90}^{L} in Figure C.8), depending on distributions of parameter values.

The parameter value assumptions for this analytical example are listed in Table C.9, and the calculated flow is shown in Figure C.9, with the parameters indicated that are treated probabilistically. Based on 100 Monte Carlo runs, the mean dose estimate is 4.2 μSv/yr and the mean derived level is 2.9 Bq/g. Dose estimates from the runs are plott ed in Figure C.10, which has a line drawn to indicate the 50th percentile in the dose distribution. Under the assumed parameter ranges, all of the doses would be less than 9 μSv/yr, with a release level of about 1 Bq/g for Co-60.

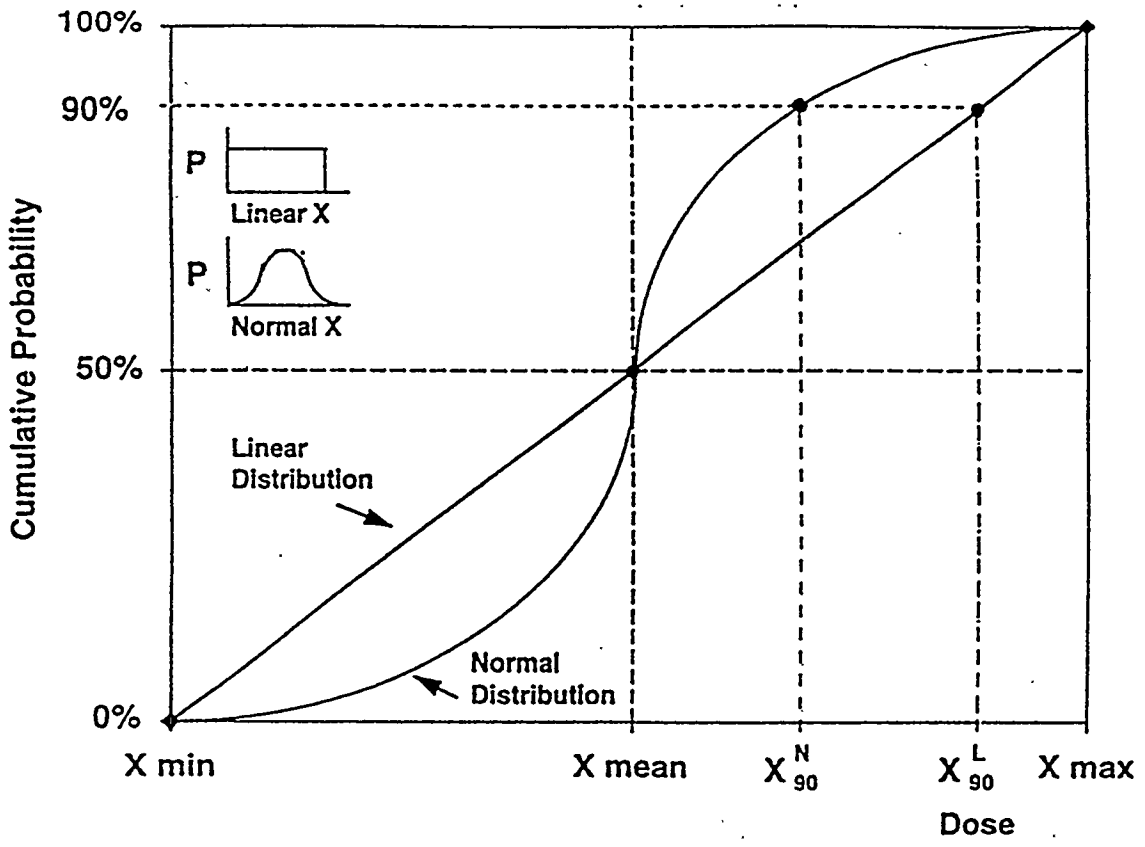


FIGURE C.8 Parameter Range and Shape of Distribution in Probabilistic Analysis

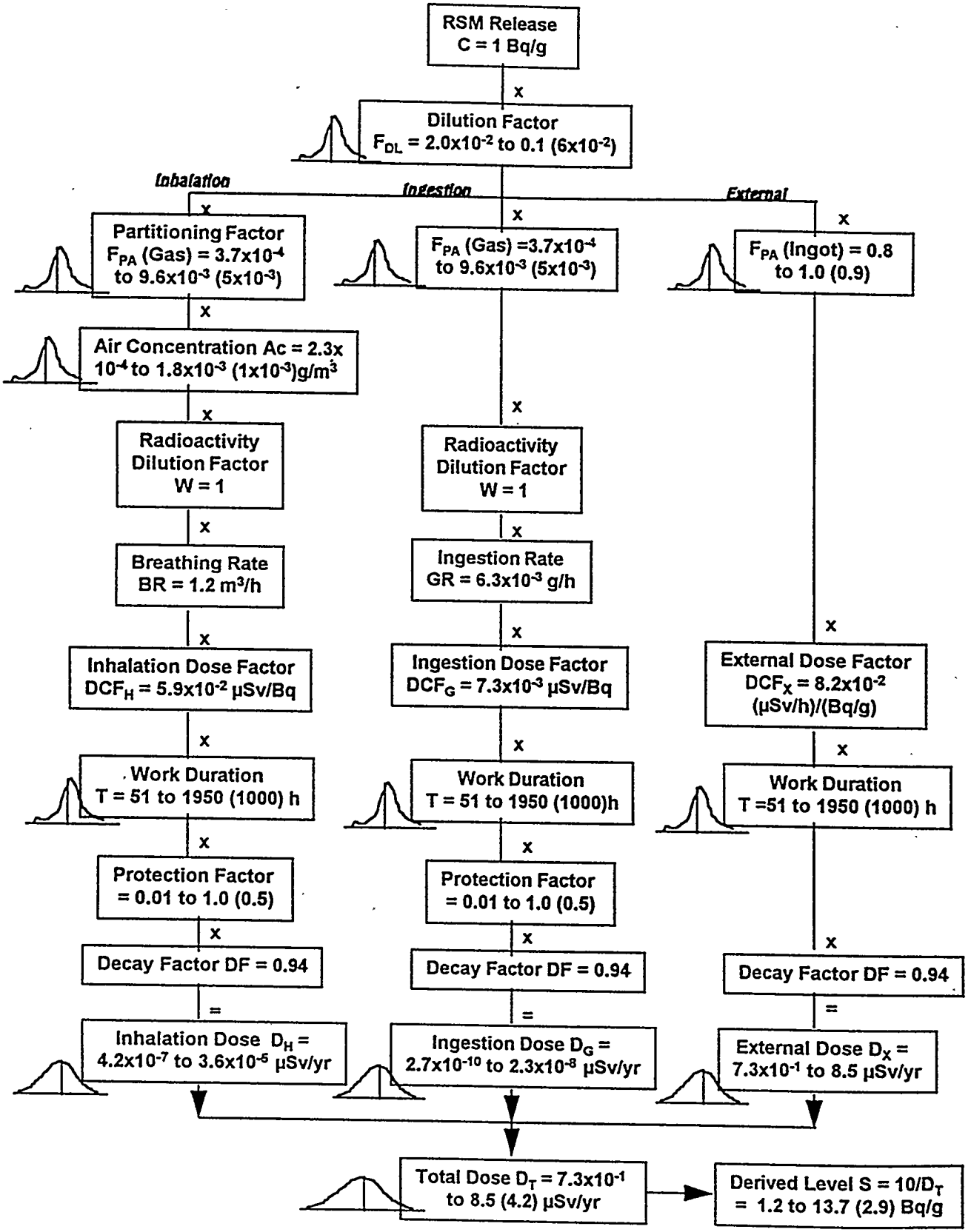


FIGURE C.9 Probabilistic Parameters in Worker Dose Calculation for Co-60 by Using Simulated Data (mean values in parentheses)

TABLE C.9 Assumptions Used in Probabilistic Analysis of Dose Estimates for Co-60

Variable	Range	Assumed Mean	Distribution
Dilution factor	$2.0 \times 10^{-2} - 0.1$	6×10^{-2}	Normal
Air dust loading	$2.3 \times 10^{-4} - 1.8 \times 10^{-3}$	1×10^{-3}	Normal
Exposure duration	$5.1 \times 10^{1} - 1.95 \times 10^{3}$	1×10^{3}	Normal
Inhalation and ingestion protection factor	$1 \times 10^{-2} - 1 \times 10^{0}$	5.1×10^{-1}	Uniform
Partitioning to ingot	$8 \times 10^{-1} - 1 \times 10^{0}$	9×10^{-1}	Normal
Partitioning to air	$3.7 \times 10^{-4} - 9.6 \times 10^{-3}$	5×10^{-3}	Normal

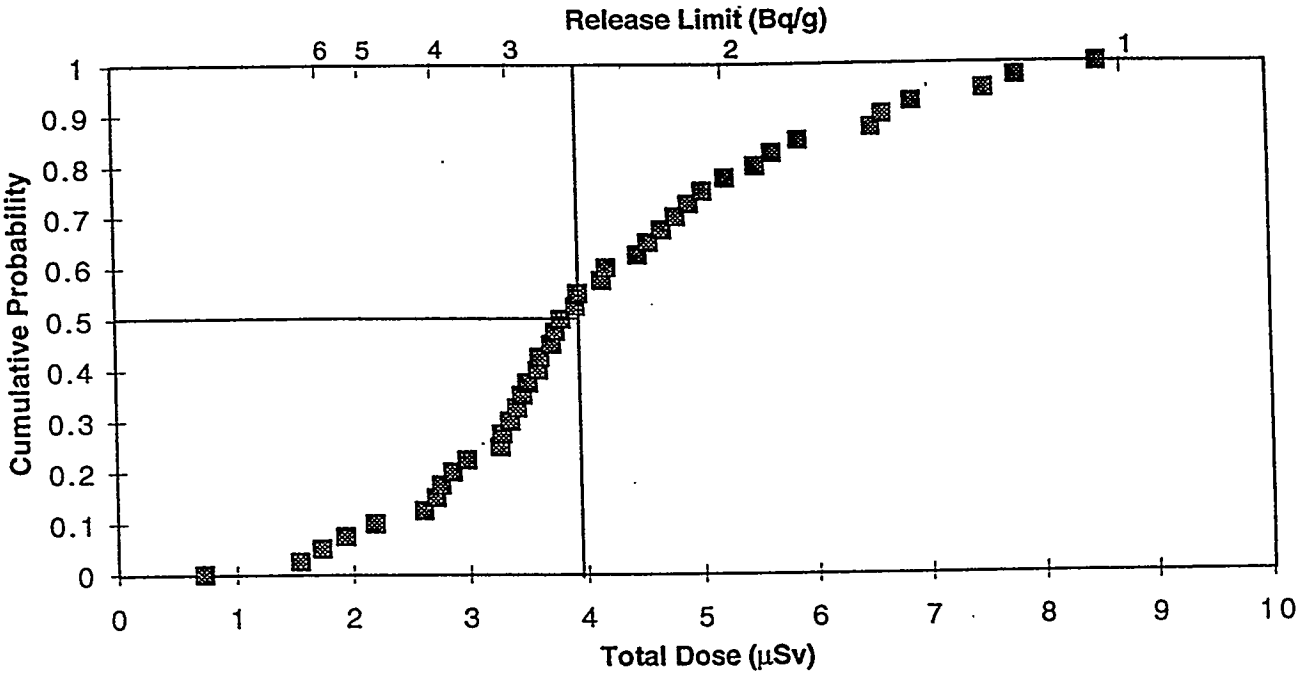


FIGURE C.10 Cumulative Probability for Co-60 Small Object Caster Dose

Because the parameter values were constructed rather than empirically based, the estimated values are not valid. However, the example demonstrates that probabilistic analysis offers a substantial advantage for development of standards in that the degree of conservatism can be controlled if parameter values are well known. In cases like that of scrap metals, where unintended conservatism is very costly, further research to characterize parameters is certainly warranted.

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APPENDIX D:

BASELINE DOSE ESTIMATES FOR WORKER AND PUBLIC SCENARIOS

APPENDIX D:

BASELINE DOSE ESTIMATES FOR WORKER AND PUBLIC SCENARIOS

The calculations presented in this appendix (Tables D.1-D.33) have been separated into worker and consumer exposures. The calculational methodology and scenarios are described in Appendix C. Individual doses have been calculated with a unit concentration of 1 Bq/g for each radionuclide on the basis of 2,000 hours of work. The worker doses presented in Tables D.1-D.22 are based on the parameters described in Table C.2. The public doses presented in Tables D.23-D.30 are based on the parameters described in Table C.3. Collective doses are based on 100 t of RSM. These baseline doses follow the scenarios and assumptions discussed in Appendix C but do not account for scrap dilution or radionuclide partitioning during melt operations, as do the modified-conservative case results given in Section 5. Doses are for an annual practice and do not include potential increases in exposures from recycling operations over time.

TABLE D.1 Baseline Worker Doses for a 2,000-h Scrap Delivery Loader[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+02	2.60E+00	4.80E+02	9.50E-04
Ag-110m	2.30E-02	3.30E-03	1.40E+01	1.40E+01	2.80E-05
Am-241	1.20E+01	2.90E+01	6.10E-02	4.10E+01	8.20E-05
Am-243	1.20E+01	2.90E+01	1.20E+00	4.20E+01	8.40E-05
Ca-41	4.30E-03	8.70E-05	0.00E+00	4.40E-03	8.80E-09
Ce-144	4.70E-02	1.60E-02	2.80E-01	3.40E-01	6.80E-07
Cl-36	1.00E-02	1.40E-03	3.10E-03	1.50E-02	2.90E-08
Cm-243	8.40E+00	2.00E+01	7.80E-01	2.90E+01	5.80E-05
Cm-244	6.70E+00	1.60E+01	1.50E-04	2.20E+01	4.50E-05
Cm-245	1.30E+01	3.00E+01	4.60E-01	4.30E+01	8.50E-05
Cm-246	1.30E+01	2.90E+01	1.30E-04	4.20E+01	8.40E-05
Cm-247	1.20E+01	2.70E+01	2.40E+00	4.10E+01	8.20E-05
Co-57	2.70E-03	3.90E-04	4.60E-01	4.60E-01	9.20E-07
Co-60	8.50E-02	1.30E-02	1.90E+01	1.90E+01	3.90E-05
Cs-134	2.10E-01	2.50E-03	1.00E+01	1.10E+01	2.10E-05
Cs-135	2.40E-02	3.00E-04	0.00E+00	2.40E-02	4.80E-08
Cs-137	1.70E-01	2.00E-03	4.30E+00	4.50E+00	9.00E-06
Eu-152	2.10E-02	1.40E-02	8.70E+00	8.80E+00	1.80E-05
Eu-154	3.10E-02	1.80E-02	9.50E+00	9.50E+00	1.90E-05
Fe-55	1.80E-03	1.50E-04	0.00E+00	2.00E-03	3.90E-09
Mn-54	6.40E-03	3.00E-04	4.50E+00	4.50E+00	9.10E-06
Na-22	3.40E-02	4.40E-04	1.50E+01	1.50E+01	3.10E-05
Nb-94	2.40E-02	2.70E-02	1.20E+01	1.20E+01	2.50E-05
Ni-59	7.10E-04	1.80E-04	0.00E+00	8.80E-04	1.80E-09
Ni-63	1.90E-03	4.10E-04	0.00E+00	2.40E-03	4.70E-09
Np-237	1.50E+01	3.50E+01	1.50E+00	5.10E+01	1.00E-04
Pb-210	1.80E+01	8.70E-01	3.30E-03	1.90E+01	3.70E-05
Pm-147	3.10E-03	2.20E-03	6.00E-05	5.40E-03	1.10E-08
Pu-238	1.10E+01	2.50E+01	1.80E-04	3.60E+01	7.20E-05
Pu-239	1.20E+01	2.80E+01	4.00E-04	4.00E+01	8.00E-05
Pu-240	1.20E+01	2.80E+01	1.80E-04	4.00E+01	8.00E-05
Pu-241	2.30E-01	5.20E-01	2.50E-05	7.50E-01	1.50E-06
Pu-242	1.10E+01	2.70E+01	1.60E-04	3.80E+01	7.60E-05
Ru-106	6.70E-02	2.20E-02	1.20E+00	1.30E+00	2.60E-06
Sb-125	8.40E-03	7.00E-04	2.80E+00	2.80E+00	5.60E-06
Se-79	2.90E-02	6.40E-04	0.00E+00	3.00E-02	6.00E-08
Sm-151	1.30E-03	1.90E-03	1.30E-06	3.20E-03	6.50E-09
Sr-90	4.80E-01	8.30E-02	3.00E-02	5.90E-01	1.20E-06
Tc-99	4.90E-03	5.40E-04	1.70E-04	5.70E-03	1.10E-08
Th-228	1.10E+00	1.90E+01	1.10E+01	3.10E+01	6.10E-05
Th-229	1.20E+01	1.40E+02	2.10E+00	1.50E+02	3.10E-04
Th-230	1.90E+00	2.10E+01	1.60E-03	2.30E+01	4.60E-05
Th-232	9.20E+00	1.10E+02	7.10E-04	1.20E+02	2.30E-04
U-232	4.40E+00	4.30E+01	1.20E-03	4.70E+01	9.40E-05
U-233	9.80E-01	8.80E+00	1.90E-03	9.80E+00	2.00E-05
U-234	9.60E-01	8.60E+00	5.40E-04	9.60E+00	1.90E-05
U-235	9.00E-01	8.00E+00	1.00E+00	9.90E+00	2.00E-05
U-238	8.60E-01	7.70E+00	1.70E-01	8.70E+00	1.70E-05
Zn-65	3.00E-02	8.20E-04	2.90E+00	3.00E+00	5.90E-06
Zr-93	5.60E-03	2.10E-02	0.00E+00	2.60E-02	5.30E-08

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.2 Baseline Worker Doses for a 2,000-h Scrap Delivery Truck Driver[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	2.30E+00	2.30E+00	1.20E-05
Ag-110m	0.00E+00	0.00E+00	1.20E+01	1.20E+01	6.10E-05
Am-241	0.00E+00	0.00E+00	5.70E-02	5.70E-02	2.80E-07
Am-243	0.00E+00	0.00E+00	1.10E+00	1.10E+00	5.50E-06
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	2.50E-01	2.50E-01	1.20E-06
Cl-36	0.00E+00	0.00E+00	2.80E-03	2.80E-03	1.40E-08
Cm-243	0.00E+00	0.00E+00	7.00E-01	7.00E-01	3.50E-06
Cm-244	0.00E+00	0.00E+00	1.70E-04	1.70E-04	8.60E-10
Cm-245	0.00E+00	0.00E+00	4.20E-01	4.20E-01	2.10E-06
Cm-246	0.00E+00	0.00E+00	1.70E-04	1.70E-04	8.30E-10
Cm-247	0.00E+00	0.00E+00	2.20E+00	2.20E+00	1.10E-05
Co-57	0.00E+00	0.00E+00	4.20E-01	4.20E-01	2.10E-06
Co-60	0.00E+00	0.00E+00	1.70E+01	1.70E+01	8.60E-05
Cs-134	0.00E+00	0.00E+00	9.20E+00	9.20E+00	4.60E-05
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	3.80E+00	3.80E+00	1.90E-05
Eu-152	0.00E+00	0.00E+00	7.80E+00	7.80E+00	3.90E-05
Eu-154	0.00E+00	0.00E+00	8.40E+00	8.40E+00	4.20E-05
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	4.00E+00	4.00E+00	2.00E-05
Na-22	0.00E+00	0.00E+00	1.40E+01	1.40E+01	6.80E-05
Nb-94	0.00E+00	0.00E+00	1.10E+01	1.10E+01	5.50E-05
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	1.30E+00	1.30E+00	6.60E-06
Pb-210	0.00E+00	0.00E+00	3.20E-03	3.20E-03	1.60E-08
Pm-147	0.00E+00	0.00E+00	5.50E-05	5.50E-05	2.70E-10
Pu-238	0.00E+00	0.00E+00	2.10E-04	2.10E-04	1.00E-09
Pu-239	0.00E+00	0.00E+00	3.80E-04	3.80E-04	1.90E-09
Pu-240	0.00E+00	0.00E+00	2.00E-04	2.00E-04	1.00E-09
Pu-241	0.00E+00	0.00E+00	2.30E-05	2.30E-05	1.10E-10
Pu-242	0.00E+00	0.00E+00	1.70E-04	1.70E-04	8.70E-10
Ru-106	0.00E+00	0.00E+00	1.10E+00	1.10E+00	5.40E-06
Sb-125	0.00E+00	0.00E+00	2.50E+00	2.50E+00	1.20E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	1.40E-06	1.40E-06	6.80E-12
Sr-90	0.00E+00	0.00E+00	2.60E-02	2.60E-02	1.30E-07
Tc-99	0.00E+00	0.00E+00	1.60E-04	1.60E-04	8.10E-10
Th-228	0.00E+00	0.00E+00	9.60E+00	9.60E+00	4.80E-05
Th-229	0.00E+00	0.00E+00	1.90E+00	1.90E+00	9.40E-06
Th-230	0.00E+00	0.00E+00	1.50E-03	1.50E-03	7.60E-09
Th-232	0.00E+00	0.00E+00	6.60E-04	6.60E-04	3.30E-09
U-232	0.00E+00	0.00E+00	1.10E-03	1.10E-03	5.70E-09
U-233	0.00E+00	0.00E+00	1.80E-03	1.80E-03	8.80E-09
U-234	0.00E+00	0.00E+00	5.10E-04	5.10E-04	2.60E-09
U-235	0.00E+00	0.00E+00	9.20E-01	9.20E-01	4.60E-06
U-238	0.00E+00	0.00E+00	1.50E-01	1.50E-01	7.70E-07
Zn-65	0.00E+00	0.00E+00	2.60E+00	2.60E+00	1.30E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.3 Baseline Worker Doses for a 2,000-h Scrap Cutter[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.90E+01	4.30E+02	6.00E-01	4.80E+02	8.60E-04
Ag-110m	2.30E-02	3.30E-03	3.50E+00	3.50E+00	6.30E-06
Am-241	1.20E+01	2.90E+01	3.90E-03	4.10E+01	7.40E-05
Am-243	1.20E+01	2.90E+01	5.50E-02	4.10E+01	7.40E-05
Ca-41	4.30E-03	8.70E-05	0.00E+00	4.40E-03	7.90E-09
Ce-144	4.70E-02	1.60E-02	6.20E-02	1.30E-01	2.30E-07
Cl-36	1.00E-02	1.40E-03	7.70E-04	1.20E-02	2.20E-08
Cm-243	8.40E+00	2.00E+01	1.60E-01	2.80E+01	5.10E-05
Cm-244	6.70E+00	1.60E+01	5.70E-06	2.30E+01	4.00E-05
Cm-245	1.30E+01	3.00E+01	7.40E-02	4.20E+01	7.60E-05
Cm-246	1.30E+01	2.90E+01	9.20E-06	4.20E+01	7.50E-05
Cm-247	1.20E+01	2.70E+01	1.50E-02	3.80E+01	6.90E-05
Co-57	2.60E-03	3.80E-04	7.60E-02	7.90E-02	1.40E-07
Co-60	8.50E-02	1.30E-02	4.90E+00	5.00E+00	8.90E-06
Cs-134	2.10E-01	2.60E-03	2.60E+00	2.80E+00	5.00E-06
Cs-135	2.40E-02	3.00E-04	0.00E+00	2.40E-02	4.40E-08
Cs-137	1.70E-01	2.10E-03	1.10E+00	1.30E+00	2.20E-06
Eu-152	2.10E-02	1.40E-02	2.20E+00	2.20E+00	4.00E-06
Eu-154	3.10E-02	1.80E-02	2.30E+00	2.40E+00	4.30E-06
Fe-55	1.80E-03	1.50E-04	0.00E+00	2.00E-03	3.50E-09
Mn-54	6.40E-03	3.00E-04	1.10E+00	1.10E+00	2.00E-06
Na-22	3.40E-02	4.40E-04	3.90E+00	3.90E+00	7.00E-06
Nb-94	2.40E-02	2.70E-02	3.10E+00	3.20E+00	5.70E-06
Ni-59	7.10E-04	1.80E-04	0.00E+00	8.80E-04	1.60E-09
Ni-63	1.90E-03	4.10E-04	0.00E+00	2.40E-03	4.20E-09
Np-237	1.50E+01	3.50E+01	3.20E-01	5.00E+01	9.10E-05
Pb-210	2.40E+01	1.50E+00	4.70E-04	2.60E+01	4.60E-05
Pm-147	3.10E-03	2.20E-03	9.90E-06	5.40E-03	9.60E-09
Pu-238	1.10E+01	2.50E+01	1.30E-05	3.60E+01	6.50E-05
Pu-239	1.20E+01	2.80E+01	7.30E-05	4.00E+01	7.20E-05
Pu-240	1.20E+01	2.80E+01	1.30E-05	4.00E+01	7.20E-05
Pu-241	2.30E-01	5.20E-01	1.40E-01	8.90E-01	1.60E-06
Pu-242	1.10E+01	2.70E+01	1.30E-05	3.80E+01	6.80E-05
Ru-106	6.70E-02	2.20E-02	4.20E+00	4.30E+00	7.80E-06
Sb-125	8.40E-03	7.00E-04	6.90E-01	7.00E-01	1.30E-06
Se-79	2.90E-02	6.40E-04	0.00E+00	3.00E-02	5.40E-08
Sm-151	1.30E-03	1.90E-03	5.10E-08	3.20E-03	5.80E-09
Sr-90	5.10E-01	8.40E-02	7.60E-03	6.00E-01	1.10E-06
Tc-99	4.90E-03	5.40E-04	2.00E-05	5.50E-03	9.90E-09
Th-228	2.30E+00	1.90E+01	2.60E+00	2.40E+01	4.30E-05
Th-229	1.40E+01	1.40E+02	4.70E-01	1.50E+02	2.80E-04
Th-230	1.90E+00	2.10E+01	2.40E-04	2.30E+01	4.10E-05
Th-232	9.20E+00	1.10E+02	8.80E-05	1.20E+02	2.10E-04
U-232	4.40E+00	4.30E+01	1.90E-04	4.70E+01	8.50E-05
U-233	9.80E-01	8.80E+00	3.70E-04	9.80E+00	1.80E-05
U-234	9.60E-01	8.60E+00	6.80E-05	9.60E+00	1.70E-05
U-235	9.00E-01	8.00E+00	2.10E-01	9.10E+00	1.60E-05
U-238	9.10E-01	7.70E+00	3.90E-02	8.60E+00	1.60E-05
Zn-65	3.00E-02	8.20E-04	7.40E-01	7.70E-01	1.40E-06
Zr-93	5.60E-03	2.10E-02	0.00E+00	2.60E-02	4.80E-08

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.4 Baseline Worker Doses for a 2,000-h Scrap Processor[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+02	6.10E-01	4.70E+02	1.40E-03
Ag-110m	2.30E-02	3.30E-03	3.20E+00	3.30E+00	9.80E-06
Am-241	1.20E+01	2.90E+01	1.50E-02	4.10E+01	1.20E-04
Am-243	1.20E+01	2.90E+01	2.90E-01	4.10E+01	1.20E-04
Ca-41	4.30E-03	8.70E-05	0.00E+00	4.40E-03	1.30E-08
Ce-144	4.70E-02	1.60E-02	6.50E-02	1.30E-01	3.80E-07
Cl-36	1.00E-02	1.40E-03	7.30E-04	1.20E-02	3.70E-08
Cm-243	8.40E+00	2.00E+01	1.80E-01	2.80E+01	8.50E-05
Cm-244	6.70E+00	1.60E+01	4.50E-05	2.20E+01	6.70E-05
Cm-245	1.30E+01	3.00E+01	1.10E-01	4.20E+01	1.30E-04
Cm-246	1.30E+01	2.90E+01	4.40E-05	4.20E+01	1.30E-04
Cm-247	1.20E+01	2.70E+01	5.70E-01	3.90E+01	1.20E-04
Co-57	2.70E-03	3.90E-04	1.10E-01	1.10E-01	3.40E-07
Co-60	8.50E-02	1.30E-02	4.50E+00	4.60E+00	1.40E-05
Cs-134	2.10E-01	2.50E-03	2.40E+00	2.60E+00	7.90E-06
Cs-135	2.40E-02	3.00E-04	0.00E+00	2.40E-02	7.30E-08
Cs-137	1.70E-01	2.00E-03	1.00E+00	1.20E+00	3.50E-06
Eu-152	2.10E-02	1.40E-02	2.00E+00	2.10E+00	6.20E-06
Eu-154	3.10E-02	1.80E-02	2.20E+00	2.30E+00	6.80E-06
Fe-55	1.80E-03	1.50E-04	0.00E+00	2.00E-03	5.90E-09
Mn-54	6.40E-03	3.00E-04	1.10E+00	1.10E+00	3.20E-06
Na-22	3.40E-02	4.40E-04	3.60E+00	3.60E+00	1.10E-05
Nb-94	2.40E-02	2.70E-02	2.90E+00	3.00E+00	8.90E-06
Ni-59	7.10E-04	1.80E-04	0.00E+00	8.80E-04	2.70E-09
Ni-63	1.90E-03	4.10E-04	0.00E+00	2.40E-03	7.10E-09
Np-237	1.50E+01	3.50E+01	3.40E-01	5.00E+01	1.50E-04
Pb-210	1.80E+01	8.70E-01	8.30E-04	1.90E+01	5.60E-05
Pm-147	3.10E-03	2.20E-03	1.40E-05	5.40E-03	1.60E-08
Pu-238	1.10E+01	2.50E+01	5.40E-05	3.60E+01	1.10E-04
Pu-239	1.20E+01	2.80E+01	9.80E-05	4.00E+01	1.20E-04
Pu-240	1.20E+01	2.80E+01	5.20E-05	4.00E+01	1.20E-04
Pu-241	2.30E-01	5.20E-01	6.00E-06	7.50E-01	2.20E-06
Pu-242	1.10E+01	2.70E+01	4.60E-05	3.80E+01	1.10E-04
Ru-106	6.70E-02	2.20E-02	2.80E-01	3.70E-01	1.10E-06
Sb-125	8.40E-03	7.00E-04	6.60E-01	6.60E-01	2.00E-06
Se-79	2.90E-02	6.40E-04	0.00E+00	3.00E-02	9.00E-08
Sm-151	1.30E-03	1.90E-03	3.60E-07	3.20E-03	9.70E-09
Sr-90	4.80E-01	8.30E-02	7.00E-03	5.70E-01	1.70E-06
Tc-99	4.90E-03	5.40E-04	4.20E-05	5.50E-03	1.70E-08
Th-228	1.10E+00	1.90E+01	2.50E+00	2.20E+01	6.70E-05
Th-229	1.20E+01	1.40E+02	4.90E-01	1.50E+02	4.50E-04
Th-230	1.90E+00	2.10E+01	4.00E-04	2.30E+01	6.90E-05
Th-232	9.20E+00	1.10E+02	1.70E-04	1.20E+02	3.50E-04
U-232	4.40E+00	4.30E+01	3.00E-04	4.70E+01	1.40E-04
U-233	9.80E-01	8.80E+00	4.60E-04	9.80E+00	2.90E-05
U-234	9.60E-01	8.60E+00	1.30E-04	9.50E+00	2.90E-05
U-235	9.00E-01	8.00E+00	2.40E-01	9.10E+00	2.70E-05
U-238	8.60E-01	7.70E+00	4.00E-02	8.60E+00	2.60E-05
Zn-65	3.00E-02	8.20E-04	6.90E-01	7.20E-01	2.10E-06
Zr-93	5.60E-03	2.10E-02	0.00E+00	2.60E-02	7.90E-08

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.5 Baseline Worker Doses for a 2,000-h Smelting Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+02	8.00E-01	4.70E+02	4.70E-03
Ag-110m	2.30E-02	3.30E-03	4.40E+00	4.40E+00	4.40E-05
Am-241	1.20E+01	2.90E+01	1.70E-02	4.10E+01	4.10E-04
Am-243	1.20E+01	2.90E+01	3.70E-01	4.10E+01	4.10E-04
Ca-41	4.30E-03	8.70E-05	0.00E+00	4.40E-03	4.40E-08
Ce-144	4.70E-02	1.60E-02	8.70E-02	1.50E-01	1.50E-06
Cl-36	1.00E-02	1.40E-03	9.80E-04	1.30E-02	1.30E-07
Cm-243	8.40E+00	2.00E+01	2.40E-01	2.80E+01	2.80E-04
Cm-244	6.70E+00	1.60E+01	2.80E-05	2.20E+01	2.20E-04
Cm-245	1.30E+01	3.00E+01	1.40E-01	4.20E+01	4.20E-04
Cm-246	1.30E+01	2.90E+01	1.90E-05	4.20E+01	4.20E-04
Cm-247	1.20E+01	2.70E+01	7.60E-01	3.90E+01	3.90E-04
Co-57	2.70E-03	3.90E-04	1.40E-01	1.40E-01	1.40E-06
Co-60	8.50E-02	1.30E-02	6.20E+00	6.30E+00	6.30E-05
Cs-134	2.10E-01	2.50E-03	3.30E+00	3.50E+00	3.50E-05
Cs-135	2.40E-02	3.00E-04	0.00E+00	2.40E-02	2.40E-07
Cs-137	1.70E-01	2.00E-03	1.40E+00	1.50E+00	1.50E-05
Eu-152	2.10E-02	1.40E-02	2.80E+00	2.80E+00	2.80E-05
Eu-154	3.10E-02	1.80E-02	3.00E+00	3.00E+00	3.00E-05
Fe-55	1.80E-03	1.50E-04	0.00E+00	2.00E-03	2.00E-08
Mn-54	6.40E-03	3.00E-04	1.40E+00	1.40E+00	1.40E-05
Na-22	3.40E-02	4.40E-04	4.90E+00	4.90E+00	4.90E-05
Nb-94	2.40E-02	2.70E-02	3.90E+00	4.00E+00	4.00E-05
Ni-59	7.10E-04	1.80E-04	0.00E+00	8.80E-04	8.80E-09
Ni-63	1.90E-03	4.10E-04	0.00E+00	2.40E-03	2.40E-08
Np-237	1.50E+01	3.50E+01	4.50E-01	5.00E+01	5.00E-04
Pb-210	1.80E+01	8.70E-01	9.20E-04	1.90E+01	1.90E-04
Pm-147	3.10E-03	2.20E-03	1.80E-05	5.40E-03	5.40E-08
Pu-238	1.10E+01	2.50E+01	4.00E-05	3.60E+01	3.60E-04
Pu-239	1.20E+01	2.80E+01	1.20E-04	4.00E+01	4.00E-04
Pu-240	1.20E+01	2.80E+01	4.00E-05	4.00E+01	4.00E-04
Pu-241	2.30E-01	5.20E-01	7.60E-06	7.50E-01	7.50E-06
Pu-242	1.10E+01	2.70E+01	3.60E-05	3.80E+01	3.80E-04
Ru-106	6.70E-02	2.20E-02	3.80E-01	4.70E-01	4.70E-06
Sb-125	8.40E-03	7.00E-04	8.80E-01	8.90E-01	8.90E-06
Se-79	2.90E-02	6.40E-04	0.00E+00	3.00E-02	3.00E-07
Sm-151	1.30E-03	1.90E-03	2.50E-07	3.20E-03	3.20E-08
Sr-90	4.80E-01	8.30E-02	9.50E-03	5.70E-01	5.70E-06
Tc-99	4.90E-03	5.40E-04	5.10E-05	5.50E-03	5.50E-08
Th-228	1.10E+00	1.90E+01	3.50E+00	2.30E+01	2.30E-04
Th-229	1.20E+01	1.40E+02	6.50E-01	1.50E+02	1.50E-03
Th-230	1.90E+00	2.10E+01	4.90E-04	2.30E+01	2.30E-04
Th-232	9.20E+00	1.10E+02	2.10E-04	1.20E+02	1.20E-03
U-232	4.40E+00	4.30E+01	3.60E-04	4.70E+01	4.70E-04
U-233	9.80E-01	8.80E+00	5.70E-04	9.80E+00	9.80E-05
U-234	9.60E-01	8.60E+00	1.60E-04	9.50E+00	9.50E-05
U-235	9.00E-01	8.00E+00	3.10E-01	9.20E+00	9.20E-05
U-238	8.60E-01	7.70E+00	5.30E-02	8.60E+00	8.60E-05
Zn-65	3.00E-02	8.20E-04	9.30E-01	9.70E-01	9.70E-06
Zr-93	5.60E-03	2.10E-02	0.00E+00	2.60E-02	2.60E-07

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.6 Baseline Worker Doses for a 2,000-h Smelting Loader[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+03	3.10E+00	4.30E+03	2.20E-02
Ag-110m	2.30E-02	3.30E-02	1.60E+01	1.70E+01	8.30E-05
Am-241	1.20E+01	2.90E+02	7.10E-02	3.00E+02	1.50E-03
Am-243	1.20E+01	2.90E+02	1.40E+00	3.00E+02	1.50E-03
Ca-41	4.30E-03	8.70E-04	0.00E+00	5.20E-03	2.60E-08
Ce-144	4.70E-02	1.60E-01	3.30E-01	5.40E-01	2.70E-06
Cl-36	1.00E-02	1.40E-02	3.70E-03	2.80E-02	1.40E-07
Cm-243	8.40E+00	2.00E+02	9.20E-01	2.10E+02	1.00E-03
Cm-244	6.70E+00	1.60E+02	1.70E-04	1.60E+02	8.20E-04
Cm-245	1.30E+01	3.00E+02	5.50E-01	3.10E+02	1.50E-03
Cm-246	1.30E+01	2.90E+02	1.50E-04	3.10E+02	1.50E-03
Cm-247	1.20E+01	2.70E+02	2.90E+00	2.80E+02	1.40E-03
Co-57	2.70E-03	3.90E-03	5.40E-01	5.50E-01	2.70E-06
Co-60	8.50E-02	1.30E-01	2.30E+01	2.30E+01	1.20E-04
Cs-134	2.10E-01	2.50E-02	1.20E+01	1.30E+01	6.30E-05
Cs-135	2.40E-02	3.00E-03	0.00E+00	2.70E-02	1.30E-07
Cs-137	1.70E-01	2.00E-02	5.10E+00	5.30E+00	2.70E-05
Eu-152	2.10E-02	1.40E-01	1.00E+01	1.10E+01	5.30E-05
Eu-154	3.10E-02	1.80E-01	1.10E+01	1.10E+01	5.70E-05
Fe-55	1.80E-03	1.50E-03	0.00E+00	3.30E-03	1.70E-08
Mn-54	6.40E-03	3.00E-03	5.40E+00	5.40E+00	2.70E-05
Na-22	3.40E-02	4.40E-03	1.80E+01	1.80E+01	9.20E-05
Nb-94	2.40E-02	2.70E-01	1.50E+01	1.50E+01	7.50E-05
Ni-59	7.10E-04	1.80E-03	0.00E+00	2.50E-03	1.20E-08
Ni-63	1.90E-03	4.10E-03	0.00E+00	6.00E-03	3.00E-08
Np-237	1.50E+01	3.50E+02	1.70E+00	3.70E+02	1.80E-03
Pb-210	1.80E+01	8.70E+00	3.90E-03	2.70E+01	1.30E-04
Pm-147	3.10E-03	2.20E-02	7.10E-05	2.60E-02	1.30E-07
Pu-238	1.10E+01	2.50E+02	2.10E-04	2.60E+02	1.30E-03
Pu-239	1.20E+01	2.80E+02	4.80E-04	2.90E+02	1.50E-03
Pu-240	1.20E+01	2.80E+02	2.10E-04	2.90E+02	1.50E-03
Pu-241	2.30E-01	5.20E+00	3.00E-05	5.40E+00	2.70E-05
Pu-242	1.10E+01	2.70E+02	1.90E-04	2.80E+02	1.40E-03
Ru-106	6.70E-02	2.20E-01	1.40E+00	1.70E+00	8.60E-06
Sb-125	8.40E-03	7.00E-03	3.30E+00	3.30E+00	1.70E-05
Se-79	2.90E-02	6.40E-03	0.00E+00	3.60E-02	1.80E-07
Sm-151	1.30E-03	1.90E-02	1.50E-06	2.10E-02	1.00E-07
Sr-90	4.80E-01	8.30E-01	3.60E-02	1.30E+00	6.70E-06
Tc-99	4.90E-03	5.40E-03	2.10E-04	1.10E-02	5.30E-08
Th-228	1.10E+00	1.90E+02	1.30E+01	2.00E+02	1.00E-03
Th-229	1.20E+01	1.40E+03	2.50E+00	1.40E+03	7.00E-03
Th-230	1.90E+00	2.10E+02	1.90E-03	2.10E+02	1.10E-03
Th-232	9.20E+00	1.10E+03	8.40E-04	1.10E+03	5.40E-03
U-232	4.40E+00	4.30E+02	1.40E-03	4.30E+02	2.10E-03
U-233	9.80E-01	8.80E+01	2.30E-03	8.90E+01	4.40E-04
U-234	9.60E-01	8.60E+01	6.40E-04	8.70E+01	4.30E-04
U-235	9.00E-01	8.00E+01	1.20E+00	8.20E+01	4.10E-04
U-238	8.60E-01	7.70E+01	2.00E-01	7.80E+01	3.90E-04
Zn-65	3.00E-02	8.20E-03	3.50E+00	3.50E+00	1.80E-05
Zr-93	5.60E-03	2.10E-01	0.00E+00	2.10E-01	1.10E-06

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.7 Baseline Worker Doses for a 2,000-h Smelting Operator[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+03	2.00E-02	4.30E+03	1.30E-02
Ag-110m	2.30E-02	3.30E-02	9.20E-01	9.70E-01	2.90E-06
Am-241	1.20E+01	2.90E+02	1.10E-10	3.00E+02	9.00E-04
Am-243	1.20E+01	2.90E+02	1.20E-03	3.00E+02	8.90E-04
Ca-41	4.30E-03	8.70E-04	0.00E+00	5.20E-03	1.60E-08
Ce-144	4.70E-02	1.60E-01	3.30E-02	2.40E-01	7.20E-07
Cl-36	1.00E-02	1.40E-02	5.30E-05	2.50E-02	7.40E-08
Cm-243	8.40E+00	2.00E+02	8.50E-04	2.10E+02	6.20E-04
Cm-244	6.70E+00	1.60E+02	3.10E-14	1.60E+02	4.90E-04
Cm-245	1.30E+01	3.00E+02	3.00E-05	3.10E+02	9.20E-04
Cm-246	1.30E+01	2.90E+02	1.80E-19	3.10E+02	9.20E-04
Cm-247	1.20E+01	2.70E+02	1.90E-02	2.80E+02	8.40E-04
Co-57	2.70E-03	3.90E-03	2.70E-04	6.90E-03	2.10E-08
Co-60	8.50E-02	1.30E-01	2.10E+00	2.30E+00	6.90E-06
Cs-134	2.10E-01	2.50E-02	4.20E-01	6.50E-01	2.00E-06
Cs-135	2.40E-02	3.00E-03	0.00E+00	2.70E-02	8.00E-08
Cs-137	1.70E-01	2.00E-02	1.40E-01	3.30E-01	9.80E-07
Eu-152	2.10E-02	1.40E-01	6.80E-01	8.50E-01	2.50E-06
Eu-154	3.10E-02	1.80E-01	7.50E-01	9.60E-01	2.90E-06
Fe-55	1.80E-03	1.50E-03	0.00E+00	3.30E-03	1.00E-08
Mn-54	6.40E-03	3.00E-03	2.40E-01	2.50E-01	7.40E-07
Na-22	3.40E-02	4.40E-03	1.10E+00	1.10E+00	3.40E-06
Nb-94	2.40E-02	2.70E-01	6.00E-01	8.90E-01	2.70E-06
Ni-59	7.10E-04	1.80E-03	0.00E+00	2.50E-03	7.40E-09
Ni-63	1.90E-03	4.10E-03	0.00E+00	6.00E-03	1.80E-08
Np-237	1.50E+01	3.50E+02	4.50E-03	3.70E+02	1.10E-03
Pb-210	1.80E+01	8.70E+00	2.10E-16	2.70E+01	8.00E-05
Pm-147	3.10E-03	2.20E-02	1.80E-09	2.50E-02	7.60E-08
Pu-238	1.10E+01	2.50E+02	1.90E-14	2.60E+02	7.90E-04
Pu-239	1.20E+01	2.80E+02	6.80E-09	2.90E+02	8.70E-04
Pu-240	1.20E+01	2.80E+02	9.50E-15	2.90E+02	8.70E-04
Pu-241	2.30E-01	5.20E+00	1.00E-08	5.40E+00	1.60E-05
Pu-242	1.10E+01	2.70E+02	3.60E-14	2.80E+02	8.30E-04
Ru-106	6.70E-02	2.20E-01	4.00E-02	3.30E-01	9.90E-07
Sb-125	8.40E-03	7.00E-03	5.40E-02	7.00E-02	2.10E-07
Se-79	2.90E-02	6.40E-03	0.00E+00	3.60E-02	1.10E-07
Sm-151	1.30E-03	1.90E-02	0.00E+00	2.10E-02	6.20E-08
Sr-90	4.80E-01	8.30E-01	5.10E-03	1.30E+00	3.90E-06
Tc-99	4.90E-03	5.40E-03	3.70E-10	1.00E-02	3.10E-08
Th-228	1.10E+00	1.90E+02	2.10E+00	1.90E+02	5.70E-04
Th-229	1.20E+01	1.40E+03	5.60E-02	1.40E+03	4.20E-03
Th-230	1.90E+00	2.10E+02	1.80E-07	2.10E+02	6.40E-04
Th-232	9.20E+00	1.10E+03	1.50E-08	1.10E+03	3.20E-03
U-232	4.40E+00	4.30E+02	7.40E-08	4.30E+02	1.30E-03
U-233	9.80E-01	8.80E+01	3.70E-08	8.90E+01	2.70E-04
U-234	9.60E-01	8.60E+01	1.20E-08	8.70E+01	2.60E-04
U-235	9.00E-01	8.00E+01	3.00E-04	8.10E+01	2.40E-04
U-238	8.60E-01	7.70E+01	8.70E-03	7.80E+01	2.30E-04
Zn-65	3.00E-02	8.20E-03	2.50E-01	2.90E-01	8.60E-07
Zr-93	5.60E-03	2.10E-01	0.00E+00	2.10E-01	6.40E-07

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.8 Baseline Worker Doses for a 2,000-h Baghouse Processor[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.90E+01	4.30E+03	2.00E+02	4.60E+03	2.30E-04
Ag-110m	2.30E-02	3.30E-02	1.20E+03	1.20E+03	5.70E-05
Am-241	1.20E+01	2.90E+02	1.40E+00	3.00E+02	1.50E-05
Am-243	1.20E+01	2.90E+02	1.90E+01	3.20E+02	1.60E-05
Ca-41	4.30E-03	8.70E-04	0.00E+00	5.20E-03	2.60E-10
Ce-144	4.70E-02	1.60E-01	2.10E+01	2.10E+01	1.00E-06
Cl-36	1.00E-02	1.40E-02	2.60E-01	2.80E-01	1.40E-08
Cm-243	8.40E+00	2.00E+02	5.50E+01	2.60E+02	1.30E-05
Cm-244	6.70E+00	1.60E+02	2.00E-03	1.60E+02	8.20E-06
Cm-245	1.30E+01	3.00E+02	2.60E+01	3.30E+02	1.70E-05
Cm-246	1.30E+01	2.90E+02	3.20E-03	3.10E+02	1.50E-05
Cm-247	1.20E+01	2.70E+02	5.10E+00	2.90E+02	1.40E-05
Co-57	2.60E-03	3.80E-03	2.60E+01	2.60E+01	1.30E-06
Co-60	8.50E-02	1.30E-01	1.60E+03	1.60E+03	8.00E-05
Cs-134	2.10E-01	2.60E-02	8.60E+02	8.60E+02	4.30E-05
Cs-135	2.40E-02	3.00E-03	0.00E+00	2.70E-02	1.30E-09
Cs-137	1.70E-01	2.10E-02	3.60E+02	3.60E+02	1.80E-05
Eu-152	2.10E-02	1.40E-01	7.20E+02	7.20E+02	3.60E-05
Eu-154	3.10E-02	1.80E-01	7.80E+02	7.80E+02	3.90E-05
Fe-55	1.80E-03	1.50E-03	0.00E+00	3.30E-03	1.70E-10
Mn-54	6.40E-03	3.00E-03	3.80E+02	3.80E+02	1.90E-05
Na-22	3.40E-02	4.40E-03	1.30E+03	1.30E+03	6.40E-05
Nb-94	2.40E-02	2.70E-01	1.00E+03	1.00E+03	5.20E-05
Ni-59	7.10E-04	1.80E-03	0.00E+00	2.50E-03	1.20E-10
Ni-63	1.90E-03	4.10E-03	0.00E+00	6.00E-03	3.00E-10
Np-237	1.50E+01	3.50E+02	1.10E+02	4.80E+02	2.40E-05
Pb-210	2.40E+01	1.50E+01	1.60E-01	3.90E+01	2.00E-06
Pm-147	3.10E-03	2.20E-02	3.40E-03	2.90E-02	1.40E-09
Pu-238	1.10E+01	2.50E+02	4.60E-03	2.60E+02	1.30E-05
Pu-239	1.20E+01	2.80E+02	2.50E-02	2.90E+02	1.50E-05
Pu-240	1.20E+01	2.80E+02	4.60E-03	2.90E+02	1.50E-05
Pu-241	2.30E-01	5.20E+00	4.90E+01	5.50E+01	2.70E-06
Pu-242	1.10E+01	2.70E+02	4.40E-03	2.80E+02	1.40E-05
Ru-106	6.70E-02	2.20E-01	1.40E+03	1.40E+03	7.10E-05
Sb-125	8.40E-03	7.00E-03	2.30E+02	2.30E+02	1.20E-05
Se-79	2.90E-02	6.40E-03	0.00E+00	3.60E-02	1.80E-09
Sm-151	1.30E-03	1.90E-02	1.80E-05	2.10E-02	1.00E-09
Sr-90	5.10E-01	8.40E-01	2.50E+00	3.80E+00	1.90E-07
Tc-99	4.90E-03	5.40E-03	6.80E-03	1.70E-02	8.60E-10
Th-228	2.30E+00	1.90E+02	8.60E+02	1.10E+03	5.20E-05
Th-229	1.40E+01	1.40E+03	1.60E+02	1.60E+03	7.90E-05
Th-230	1.90E+00	2.10E+02	8.20E-02	2.10E+02	1.10E-05
Th-232	9.20E+00	1.10E+03	3.10E-02	1.10E+03	5.40E-05
U-232	4.40E+00	4.30E+02	6.50E-02	4.30E+02	2.20E-05
U-233	9.80E-01	8.80E+01	1.30E-01	8.90E+01	4.50E-06
U-234	9.60E-01	8.60E+01	2.40E-02	8.70E+01	4.40E-06
U-235	9.00E-01	8.00E+01	7.20E+01	1.50E+02	7.60E-06
U-238	9.10E-01	7.70E+01	1.30E+01	9.10E+01	4.50E-06
Zn-65	3.00E-02	8.20E-03	2.40E+02	2.40E+02	1.20E-05
Zr-93	5.60E-03	2.10E-01	0.00E+00	2.10E-01	1.10E-08

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.9 Baseline Worker Doses for a 2,000-h Industrial Products Caster 1[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+03	9.00E+00	4.30E+03	8.70E-03
Ag-110m	2.30E-02	3.30E-02	4.80E+01	4.80E+01	9.60E-05
Am-241	1.20E+01	2.90E+02	2.20E-01	3.00E+02	6.00E-04
Am-243	1.20E+01	2.90E+02	4.20E+00	3.00E+02	6.00E-04
Ca-41	4.30E-03	8.70E-04	0.00E+00	5.20E-03	1.00E-08
Ce-144	4.70E-02	1.60E-01	9.60E-01	1.20E+00	2.30E-06
Cl-36	1.00E-02	1.40E-02	1.10E-02	3.50E-02	7.00E-08
Cm-243	8.40E+00	2.00E+02	2.70E+00	2.10E+02	4.20E-04
Cm-244	6.70E+00	1.60E+02	7.00E-04	1.60E+02	3.30E-04
Cm-245	1.30E+01	3.00E+02	1.60E+00	3.10E+02	6.20E-04
Cm-246	1.30E+01	2.90E+02	6.90E-04	3.10E+02	6.10E-04
Cm-247	1.20E+01	2.70E+02	8.40E+00	2.90E+02	5.80E-04
Co-57	2.70E-03	3.90E-03	1.60E+00	1.60E+00	3.20E-06
Co-60	8.50E-02	1.30E-01	6.70E+01	6.70E+01	1.30E-04
Cs-134	2.10E-01	2.50E-02	3.60E+01	3.60E+01	7.20E-05
Cs-135	2.40E-02	3.00E-03	0.00E+00	2.70E-02	5.40E-08
Cs-137	1.70E-01	2.00E-02	1.50E+01	1.50E+01	3.00E-05
Eu-152	2.10E-02	1.40E-01	3.00E+01	3.00E+01	6.10E-05
Eu-154	3.10E-02	1.80E-01	3.30E+01	3.30E+01	6.60E-05
Fe-55	1.80E-03	1.50E-03	0.00E+00	3.30E-03	6.70E-09
Mn-54	6.40E-03	3.00E-03	1.60E+01	1.60E+01	3.10E-05
Na-22	3.40E-02	4.40E-03	5.30E+01	5.30E+01	1.10E-04
Nb-94	2.40E-02	2.70E-01	4.30E+01	4.30E+01	8.60E-05
Ni-59	7.10E-04	1.80E-03	0.00E+00	2.50E-03	4.90E-09
Ni-63	1.90E-03	4.10E-03	0.00E+00	6.00E-03	1.20E-08
Np-237	1.50E+01	3.50E+02	5.00E+00	3.70E+02	7.40E-04
Pb-210	1.80E+01	8.70E+00	1.20E-02	2.70E+01	5.30E-05
Pm-147	3.10E-03	2.20E-02	2.10E-04	2.60E-02	5.10E-08
Pu-238	1.10E+01	2.50E+02	8.40E-04	2.60E+02	5.30E-04
Pu-239	1.20E+01	2.80E+02	1.40E-03	2.90E+02	5.80E-04
Pu-240	1.20E+01	2.80E+02	8.10E-04	2.90E+02	5.80E-04
Pu-241	2.30E-01	5.20E+00	8.80E-05	5.40E+00	1.10E-05
Pu-242	1.10E+01	2.70E+02	7.00E-04	2.80E+02	5.60E-04
Ru-106	6.70E-02	2.20E-01	4.20E+00	4.40E+00	8.90E-06
Sb-125	8.40E-03	7.00E-03	9.60E+00	9.70E+00	1.90E-05
Se-79	2.90E-02	6.40E-03	0.00E+00	3.60E-02	7.20E-08
Sm-151	1.30E-03	1.90E-02	5.40E-06	2.10E-02	4.10E-08
Sr-90	4.80E-01	8.30E-01	1.00E-01	1.40E+00	2.80E-06
Tc-99	4.90E-03	5.40E-03	6.20E-04	1.10E-02	2.20E-08
Th-228	1.10E+00	1.90E+02	3.70E+01	2.20E+02	4.50E-04
Th-229	1.20E+01	1.40E+03	7.30E+00	1.40E+03	2.80E-03
Th-230	1.90E+00	2.10E+02	5.80E-03	2.10E+02	4.30E-04
Th-232	9.20E+00	1.10E+03	2.60E-03	1.10E+03	2.10E-03
U-232	4.40E+00	4.30E+02	4.40E-03	4.30E+02	8.60E-04
U-233	9.80E-01	8.80E+01	6.80E-03	8.90E+01	1.80E-04
U-234	9.60E-01	8.60E+01	2.00E-03	8.70E+01	1.70E-04
U-235	9.00E-01	8.00E+01	3.60E+00	8.40E+01	1.70E-04
U-238	8.60E-01	7.70E+01	6.00E-01	7.80E+01	1.60E-04
Zn-65	3.00E-02	8.20E-03	1.00E+01	1.00E+01	2.00E-05
Zr-93	5.60E-03	2.10E-01	0.00E+00	2.10E-01	4.30E-07

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.10 Baseline Worker Doses for a 2,000-h Industrial Products Caster 2[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+03	3.20E+01	4.40E+03	8.70E-03
Ag-110m	2.30E-02	3.30E-02	1.10E+02	1.10E+02	2.30E-04
Am-241	1.20E+01	2.90E+02	1.60E+00	3.00E+02	6.00E-04
Am-243	1.20E+01	2.90E+02	2.20E+01	3.20E+02	6.40E-04
Ca-41	4.30E-03	8.70E-04	0.00E+00	5.20E-03	1.00E-08
Ce-144	4.70E-02	1.60E-01	2.90E+00	3.10E+00	6.10E-06
Cl-36	1.00E-02	1.40E-02	3.00E-02	5.40E-02	1.10E-07
Cm-243	8.40E+00	2.00E+02	1.20E+01	2.20E+02	4.40E-04
Cm-244	6.70E+00	1.60E+02	5.10E-03	1.60E+02	3.30E-04
Cm-245	1.30E+01	3.00E+02	9.90E+00	3.20E+02	6.40E-04
Cm-246	1.30E+01	2.90E+02	5.00E-03	3.10E+02	6.10E-04
Cm-247	1.20E+01	2.70E+02	2.60E+01	3.10E+02	6.10E-04
Co-57	2.70E-03	3.90E-03	9.50E+00	9.50E+00	1.90E-05
Co-60	8.50E-02	1.30E-01	1.50E+02	1.50E+02	2.90E-04
Cs-134	2.10E-01	2.50E-02	9.10E+01	9.10E+01	1.80E-04
Cs-135	2.40E-02	3.00E-03	0.00E+00	2.70E-02	5.40E-08
Cs-137	1.70E-01	2.00E-02	3.90E+01	3.90E+01	7.90E-05
Eu-152	2.10E-02	1.40E-01	7.50E+01	7.50E+01	1.50E-04
Eu-154	3.10E-02	1.80E-01	8.00E+01	8.00E+01	1.60E-04
Fe-55	1.80E-03	1.50E-03	0.00E+00	3.30E-03	6.70E-09
Mn-54	6.40E-03	3.00E-03	3.70E+01	3.70E+01	7.30E-05
Na-22	3.40E-02	4.40E-03	1.30E+02	1.30E+02	2.50E-04
Nb-94	2.40E-02	2.70E-01	1.00E+02	1.00E+02	2.10E-04
Ni-59	7.10E-04	1.80E-03	0.00E+00	2.50E-03	4.90E-09
Ni-63	1.90E-03	4.10E-03	0.00E+00	6.00E-03	1.20E-08
Np-237	1.50E+01	3.50E+02	1.90E+01	3.80E+02	7.70E-04
Pb-210	1.80E+01	8.70E+00	8.70E-02	2.70E+01	5.30E-05
Pm-147	3.10E-03	2.20E-02	1.30E-03	2.70E-02	5.40E-08
Pu-238	1.10E+01	2.50E+02	6.10E-03	2.60E+02	5.30E-04
Pu-239	1.20E+01	2.80E+02	9.20E-03	2.90E+02	5.80E-04
Pu-240	1.20E+01	2.80E+02	5.90E-03	2.90E+02	5.80E-04
Pu-241	2.30E-01	5.20E+00	4.90E-04	5.40E+00	1.10E-05
Pu-242	1.10E+01	2.70E+02	5.10E-03	2.80E+02	5.60E-04
Ru-106	6.70E-02	2.20E-01	1.10E+01	1.10E+01	2.30E-05
Sb-125	8.40E-03	7.00E-03	2.70E+01	2.70E+01	5.40E-05
Se-79	2.90E-02	6.40E-03	0.00E+00	3.60E-02	7.20E-08
Sm-151	1.30E-03	1.90E-02	3.90E-05	2.10E-02	4.10E-08
Sr-90	4.80E-01	8.30E-01	2.10E-01	1.50E+00	3.00E-06
Tc-99	4.90E-03	5.40E-03	4.30E-03	1.50E-02	2.90E-08
Th-228	1.10E+00	1.90E+02	8.30E+01	2.70E+02	5.40E-04
Th-229	1.20E+01	1.40E+03	2.70E+01	1.40E+03	2.90E-03
Th-230	1.90E+00	2.10E+02	3.50E-02	2.10E+02	4.30E-04
Th-232	9.20E+00	1.10E+03	1.60E-02	1.10E+03	2.10E-03
U-232	4.40E+00	4.30E+02	2.60E-02	4.30E+02	8.60E-04
U-233	9.80E-01	8.80E+01	4.30E-02	8.90E+01	1.80E-04
U-234	9.60E-01	8.60E+01	1.30E-02	8.70E+01	1.70E-04
U-235	9.00E-01	8.00E+01	1.70E+01	9.80E+01	2.00E-04
U-238	8.60E-01	7.70E+01	2.00E+00	8.00E+01	1.60E-04
Zn-65	3.00E-02	8.20E-03	2.40E+01	2.40E+01	4.80E-05
Zr-93	5.60E-03	2.10E-01	0.00E+00	2.10E-01	4.30E-07

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.11 Baseline Worker Doses for a 2,000-h Industrial Products Slag Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+02	4.30E+04	2.90E+02	4.40E+04	4.40E-02
Ag-110m	2.30E-01	3.30E-01	1.60E+03	1.60E+03	1.60E-03
Am-241	1.20E+02	2.90E+03	6.80E+00	3.00E+03	3.00E-03
Am-243	1.20E+02	2.90E+03	1.40E+02	3.10E+03	3.10E-03
Ca-41	4.30E-02	8.70E-03	0.00E+00	5.20E-02	5.20E-08
Ce-144	4.70E-01	1.60E+00	3.10E+01	3.30E+01	3.30E-05
Cl-36	1.00E-01	1.40E-01	3.60E-01	6.00E-01	6.00E-07
Cm-243	8.40E+01	2.00E+03	8.70E+01	2.10E+03	2.10E-03
Cm-244	6.70E+01	1.60E+03	2.10E-02	1.60E+03	1.60E-03
Cm-245	1.30E+02	3.00E+03	5.20E+01	3.10E+03	3.10E-03
Cm-246	1.30E+02	2.90E+03	2.00E-02	3.10E+03	3.10E-03
Cm-247	1.20E+02	2.70E+03	2.80E+02	3.10E+03	3.10E-03
Co-57	2.70E-02	3.90E-02	5.10E+01	5.10E+01	5.10E-05
Co-60	8.50E-01	1.30E+00	2.20E+03	2.20E+03	2.20E-03
Cs-134	2.10E+00	2.50E-01	1.20E+03	1.20E+03	1.20E-03
Cs-135	2.40E-01	3.00E-02	0.00E+00	2.70E-01	2.70E-07
Cs-137	1.70E+00	2.00E-01	5.00E+02	5.00E+02	5.00E-04
Eu-152	2.10E-01	1.40E+00	9.90E+02	1.00E+03	1.00E-03
Eu-154	3.10E-01	1.80E+00	1.10E+03	1.10E+03	1.10E-03
Fe-55	1.80E-02	1.50E-02	0.00E+00	3.30E-02	3.30E-08
Mn-54	6.40E-02	3.00E-02	5.20E+02	5.20E+02	5.20E-04
Na-22	3.40E-01	4.40E-02	1.70E+03	1.70E+03	1.70E-03
Nb-94	2.40E-01	2.70E+00	1.40E+03	1.40E+03	1.40E-03
Ni-59	7.10E-03	1.80E-02	0.00E+00	2.50E-02	2.50E-08
Ni-63	1.90E-02	4.10E-02	0.00E+00	6.00E-02	6.00E-08
Np-237	1.50E+02	3.50E+03	1.70E+02	3.80E+03	3.80E-03
Pb-210	1.80E+02	8.70E+01	3.80E-01	2.70E+02	2.70E-04
Pm-147	3.10E-02	2.20E-01	6.70E-03	2.60E-01	2.60E-07
Pu-238	1.10E+02	2.50E+03	2.50E-02	2.60E+03	2.60E-03
Pu-239	1.20E+02	2.80E+03	4.50E-02	2.90E+03	2.90E-03
Pu-240	1.20E+02	2.80E+03	2.40E-02	2.90E+03	2.90E-03
Pu-241	2.30E+00	5.20E+01	2.80E-03	5.40E+01	5.40E-05
Pu-242	1.10E+02	2.70E+03	2.10E-02	2.80E+03	2.80E-03
Ru-106	6.70E-01	2.20E+00	1.40E+02	1.40E+02	1.40E-04
Sb-125	8.40E-02	7.00E-02	3.20E+02	3.20E+02	3.20E-04
Se-79	2.90E-01	6.40E-02	0.00E+00	3.60E-01	3.60E-07
Sm-151	1.30E-02	1.90E-01	1.60E-04	2.10E-01	2.10E-07
Sr-90	4.80E+00	8.30E+00	3.30E+00	1.60E+01	1.60E-05
Tc-99	4.90E-02	5.40E-02	1.90E-02	1.20E-01	1.20E-07
Th-228	1.10E+01	1.90E+03	1.20E+03	3.10E+03	3.10E-03
Th-229	1.20E+02	1.40E+04	2.40E+02	1.40E+04	1.40E-02
Th-230	1.90E+01	2.10E+03	1.90E-01	2.10E+03	2.10E-03
Th-232	9.20E+01	1.10E+04	8.00E-02	1.10E+04	1.10E-02
U-232	4.40E+01	4.30E+03	1.40E-01	4.30E+03	4.30E-03
U-233	9.80E+00	8.80E+02	2.10E-01	8.90E+02	8.90E-04
U-234	9.60E+00	8.60E+02	6.20E-02	8.70E+02	8.70E-04
U-235	9.00E+00	8.00E+02	1.20E+02	9.20E+02	9.20E-04
U-238	8.60E+00	7.70E+02	2.00E+01	8.00E+02	8.00E-04
Zn-65	3.00E-01	8.20E-02	3.30E+02	3.30E+02	3.30E-04
Zr-93	5.60E-02	2.10E+00	0.00E+00	2.10E+00	2.10E-06

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.12 Baseline Worker Doses for a 2,000-h Industrial Products Loader[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	6.00E+00	6.00E+00	1.20E-05
Ag-110m	0.00E+00	0.00E+00	3.20E+01	3.20E+01	6.40E-05
Am-241	0.00E+00	0.00E+00	1.40E-01	1.40E-01	2.80E-07
Am-243	0.00E+00	0.00E+00	2.80E+00	2.80E+00	5.50E-06
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	6.40E-01	6.40E-01	1.30E-06
Cl-36	0.00E+00	0.00E+00	7.20E-03	7.20E-03	1.40E-08
Cm-243	0.00E+00	0.00E+00	1.80E+00	1.80E+00	3.60E-06
Cm-244	0.00E+00	0.00E+00	3.30E-04	3.30E-04	6.60E-10
Cm-245	0.00E+00	0.00E+00	1.10E+00	1.10E+00	2.10E-06
Cm-246	0.00E+00	0.00E+00	2.90E-04	2.90E-04	5.80E-10
Cm-247	0.00E+00	0.00E+00	5.60E+00	5.60E+00	1.10E-05
Co-57	0.00E+00	0.00E+00	1.00E+00	1.00E+00	2.10E-06
Co-60	0.00E+00	0.00E+00	4.50E+01	4.50E+01	9.00E-05
Cs-134	0.00E+00	0.00E+00	2.40E+01	2.40E+01	4.80E-05
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	1.00E+01	1.00E+01	2.00E-05
Eu-152	0.00E+00	0.00E+00	2.00E+01	2.00E+01	4.10E-05
Eu-154	0.00E+00	0.00E+00	2.20E+01	2.20E+01	4.40E-05
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	1.00E+01	1.00E+01	2.10E-05
Na-22	0.00E+00	0.00E+00	3.60E+01	3.60E+01	7.10E-05
Nb-94	0.00E+00	0.00E+00	2.90E+01	2.90E+01	5.80E-05
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	3.40E+00	3.40E+00	6.70E-06
Pb-210	0.00E+00	0.00E+00	7.60E-03	7.60E-03	1.50E-08
Pm-147	0.00E+00	0.00E+00	1.40E-04	1.40E-04	2.70E-10
Pu-238	0.00E+00	0.00E+00	4.10E-04	4.10E-04	8.20E-10
Pu-239	0.00E+00	0.00E+00	9.20E-04	9.20E-04	1.80E-09
Pu-240	0.00E+00	0.00E+00	4.00E-04	4.00E-04	8.00E-10
Pu-241	0.00E+00	0.00E+00	5.80E-05	5.80E-05	1.20E-10
Pu-242	0.00E+00	0.00E+00	3.50E-04	3.50E-04	7.10E-10
Ru-106	0.00E+00	0.00E+00	2.80E+00	2.80E+00	5.60E-06
Sb-125	0.00E+00	0.00E+00	6.50E+00	6.50E+00	1.30E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	2.80E-06	2.80E-06	5.70E-12
Sr-90	0.00E+00	0.00E+00	7.00E-02	7.00E-02	1.40E-07
Tc-99	0.00E+00	0.00E+00	4.00E-04	4.00E-04	7.90E-10
Th-228	0.00E+00	0.00E+00	2.50E+01	2.50E+01	5.10E-05
Th-229	0.00E+00	0.00E+00	4.80E+00	4.80E+00	9.70E-06
Th-230	0.00E+00	0.00E+00	3.80E-03	3.80E-03	7.50E-09
Th-232	0.00E+00	0.00E+00	1.60E-03	1.60E-03	3.20E-09
U-232	0.00E+00	0.00E+00	2.80E-03	2.80E-03	5.60E-09
U-233	0.00E+00	0.00E+00	4.40E-03	4.40E-03	8.80E-09
U-234	0.00E+00	0.00E+00	1.20E-03	1.20E-03	2.50E-09
U-235	0.00E+00	0.00E+00	2.30E+00	2.30E+00	4.70E-06
U-238	0.00E+00	0.00E+00	4.00E-01	4.00E-01	7.90E-07
Zn-65	0.00E+00	0.00E+00	6.80E+00	6.80E+00	1.40E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.13 Baseline Worker Doses for a 2,000-h Industrial Products Truck Driver[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	5.30E+00	5.30E+00	2.60E-05
Ag-110m	0.00E+00	0.00E+00	2.80E+01	2.80E+01	1.40E-04
Am-241	0.00E+00	0.00E+00	1.30E-01	1.30E-01	6.40E-07
Am-243	0.00E+00	0.00E+00	2.50E+00	2.50E+00	1.20E-05
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	5.70E-01	5.70E-01	2.80E-06
Cl-36	0.00E+00	0.00E+00	6.30E-03	6.30E-03	3.20E-08
Cm-243	0.00E+00	0.00E+00	1.60E+00	1.60E+00	8.00E-06
Cm-244	0.00E+00	0.00E+00	3.90E-04	3.90E-04	1.90E-09
Cm-245	0.00E+00	0.00E+00	9.60E-01	9.60E-01	4.80E-06
Cm-246	0.00E+00	0.00E+00	3.70E-04	3.70E-04	1.90E-09
Cm-247	0.00E+00	0.00E+00	4.90E+00	4.90E+00	2.50E-05
Co-57	0.00E+00	0.00E+00	9.50E-01	9.50E-01	4.70E-06
Co-60	0.00E+00	0.00E+00	4.00E+01	4.00E+01	2.00E-04
Cs-134	0.00E+00	0.00E+00	2.10E+01	2.10E+01	1.10E-04
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	8.80E+00	8.80E+00	4.40E-05
Eu-152	0.00E+00	0.00E+00	1.80E+01	1.80E+01	8.90E-05
Eu-154	0.00E+00	0.00E+00	1.90E+01	1.90E+01	9.70E-05
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	9.30E+00	9.30E+00	4.60E-05
Na-22	0.00E+00	0.00E+00	3.20E+01	3.20E+01	1.60E-04
Nb-94	0.00E+00	0.00E+00	2.50E+01	2.50E+01	1.30E-04
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	3.00E+00	3.00E+00	1.50E-05
Pb-210	0.00E+00	0.00E+00	7.10E-03	7.10E-03	3.60E-08
Pm-147	0.00E+00	0.00E+00	1.20E-04	1.20E-04	6.20E-10
Pu-238	0.00E+00	0.00E+00	4.70E-04	4.70E-04	2.30E-09
Pu-239	0.00E+00	0.00E+00	8.50E-04	8.50E-04	4.20E-09
Pu-240	0.00E+00	0.00E+00	4.50E-04	4.50E-04	2.30E-09
Pu-241	0.00E+00	0.00E+00	5.20E-05	5.20E-05	2.60E-10
Pu-242	0.00E+00	0.00E+00	3.90E-04	3.90E-04	2.00E-09
Ru-106	0.00E+00	0.00E+00	2.50E+00	2.50E+00	1.20E-05
Sb-125	0.00E+00	0.00E+00	5.70E+00	5.70E+00	2.90E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	3.10E-06	3.10E-06	1.50E-11
Sr-90	0.00E+00	0.00E+00	6.10E-02	6.10E-02	3.00E-07
Tc-99	0.00E+00	0.00E+00	3.60E-04	3.60E-04	1.80E-09
Th-228	0.00E+00	0.00E+00	2.20E+01	2.20E+01	1.10E-04
Th-229	0.00E+00	0.00E+00	4.30E+00	4.30E+00	2.20E-05
Th-230	0.00E+00	0.00E+00	3.40E-03	3.40E-03	1.70E-08
Th-232	0.00E+00	0.00E+00	1.50E-03	1.50E-03	7.50E-09
U-232	0.00E+00	0.00E+00	2.60E-03	2.60E-03	1.30E-08
U-233	0.00E+00	0.00E+00	4.00E-03	4.00E-03	2.00E-08
U-234	0.00E+00	0.00E+00	1.20E-03	1.20E-03	5.80E-09
U-235	0.00E+00	0.00E+00	2.10E+00	2.10E+00	1.10E-05
U-238	0.00E+00	0.00E+00	3.50E-01	3.50E-01	1.80E-06
Zn-65	0.00E+00	0.00E+00	6.00E+00	6.00E+00	3.00E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.14 Baseline Worker Doses for a 2,000-h Initial Fabrication Yard Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	1.10E+00	1.10E+00	1.10E-05
Ag-110m	0.00E+00	0.00E+00	5.80E+00	5.80E+00	5.80E-05
Am-241	0.00E+00	0.00E+00	2.20E-02	2.20E-02	2.20E-07
Am-243	0.00E+00	0.00E+00	4.80E-01	4.80E-01	4.80E-06
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	1.10E-01	1.10E-01	1.10E-06
Cl-36	0.00E+00	0.00E+00	1.30E-03	1.30E-03	1.30E-08
Cm-243	0.00E+00	0.00E+00	3.10E-01	3.10E-01	3.10E-06
Cm-244	0.00E+00	0.00E+00	3.60E-05	3.60E-05	3.60E-10
Cm-245	0.00E+00	0.00E+00	1.80E-01	1.80E-01	1.80E-06
Cm-246	0.00E+00	0.00E+00	2.50E-05	2.50E-05	2.50E-10
Cm-247	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E-05
Co-57	0.00E+00	0.00E+00	1.80E-01	1.80E-01	1.80E-06
Co-60	0.00E+00	0.00E+00	8.10E+00	8.10E+00	8.10E-05
Cs-134	0.00E+00	0.00E+00	4.30E+00	4.30E+00	4.30E-05
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	1.80E+00	1.80E+00	1.80E-05
Eu-152	0.00E+00	0.00E+00	3.60E+00	3.60E+00	3.60E-05
Eu-154	0.00E+00	0.00E+00	3.90E+00	3.90E+00	3.90E-05
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	1.90E+00	1.90E+00	1.90E-05
Na-22	0.00E+00	0.00E+00	6.40E+00	6.40E+00	6.40E-05
Nb-94	0.00E+00	0.00E+00	5.10E+00	5.10E+00	5.10E-05
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	5.90E-01	5.90E-01	5.90E-06
Pb-210	0.00E+00	0.00E+00	1.20E-03	1.20E-03	1.20E-08
Pm-147	0.00E+00	0.00E+00	2.40E-05	2.40E-05	2.40E-10
Pu-238	0.00E+00	0.00E+00	5.20E-05	5.20E-05	5.20E-10
Pu-239	0.00E+00	0.00E+00	1.50E-04	1.50E-04	1.50E-09
Pu-240	0.00E+00	0.00E+00	5.20E-05	5.20E-05	5.20E-10
Pu-241	0.00E+00	0.00E+00	9.90E-06	9.90E-06	9.90E-11
Pu-242	0.00E+00	0.00E+00	4.70E-05	4.70E-05	4.70E-10
Ru-106	0.00E+00	0.00E+00	5.00E-01	5.00E-01	5.00E-06
Sb-125	0.00E+00	0.00E+00	1.20E+00	1.20E+00	1.20E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	3.30E-07	3.30E-07	3.30E-12
Sr-90	0.00E+00	0.00E+00	1.30E-02	1.30E-02	1.30E-07
Tc-99	0.00E+00	0.00E+00	6.60E-05	6.60E-05	6.60E-10
Th-228	0.00E+00	0.00E+00	4.50E+00	4.50E+00	4.50E-05
Th-229	0.00E+00	0.00E+00	8.50E-01	8.50E-01	8.50E-06
Th-230	0.00E+00	0.00E+00	6.40E-04	6.40E-04	6.40E-09
Th-232	0.00E+00	0.00E+00	2.70E-04	2.70E-04	2.70E-09
U-232	0.00E+00	0.00E+00	4.70E-04	4.70E-04	4.70E-09
U-233	0.00E+00	0.00E+00	7.50E-04	7.50E-04	7.50E-09
U-234	0.00E+00	0.00E+00	2.10E-04	2.10E-04	2.00E-09
U-235	0.00E+00	0.00E+00	4.10E-01	4.10E-01	4.10E-06
U-238	0.00E+00	0.00E+00	7.00E-02	7.00E-02	7.00E-07
Zn-65	0.00E+00	0.00E+00	1.20E+00	1.20E+00	1.20E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.15 Baseline Worker Doses for a 2,000-h Initial Fabrication Sheet Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+02	2.70E+00	4.80E+02	7.20E-03
Ag-110m	2.30E-02	3.30E-03	7.90E+00	8.00E+00	1.20E-04
Am-241	1.20E+01	2.90E+01	5.30E-01	4.20E+01	6.20E-04
Am-243	1.20E+01	2.90E+01	2.80E+00	4.40E+01	6.50E-04
Ca-41	4.30E-03	8.70E-05	0.00E+00	4.40E-03	6.60E-08
Ce-144	4.70E-02	1.60E-02	2.50E-01	3.10E-01	4.60E-06
Cl-36	1.00E-02	1.40E-03	2.10E-03	1.40E-02	2.10E-07
Cm-243	8.40E+00	2.00E+01	1.10E+00	2.90E+01	4.40E-04
Cm-244	6.70E+00	1.60E+01	1.90E-03	2.20E+01	3.40E-04
Cm-245	1.30E+01	3.00E+01	1.10E+00	4.30E+01	6.50E-04
Cm-246	1.30E+01	2.90E+01	1.90E-03	4.20E+01	6.30E-04
Cm-247	1.20E+01	2.70E+01	1.90E+00	4.00E+01	6.00E-04
Co-57	2.70E-03	3.90E-04	9.50E-01	9.50E-01	1.40E-05
Co-60	8.50E-02	1.30E-02	1.00E+01	1.00E+01	1.50E-04
Cs-134	2.10E-01	2.50E-03	6.30E+00	6.50E+00	9.70E-05
Cs-135	2.40E-02	3.00E-04	0.00E+00	2.40E-02	3.60E-07
Cs-137	1.70E-01	2.00E-03	2.70E+00	2.80E+00	4.30E-05
Eu-152	2.10E-02	1.40E-02	5.50E+00	5.50E+00	8.30E-05
Eu-154	3.10E-02	1.80E-02	5.80E+00	5.90E+00	8.80E-05
Fe-55	1.80E-03	1.50E-04	0.00E+00	2.00E-03	2.90E-08
Mn-54	6.40E-03	3.00E-04	2.60E+00	2.60E+00	3.90E-05
Na-22	3.40E-02	4.40E-04	8.90E+00	8.90E+00	1.30E-04
Nb-94	2.40E-02	2.70E-02	7.20E+00	7.30E+00	1.10E-04
Ni-59	7.10E-04	1.80E-04	0.00E+00	8.80E-04	1.30E-08
Ni-63	1.90E-03	4.10E-04	0.00E+00	2.40E-03	3.50E-08
Np-237	1.50E+01	3.50E+01	1.80E+00	5.20E+01	7.80E-04
Pb-210	1.80E+01	8.70E-01	3.20E-02	1.90E+01	2.80E-04
Pm-147	3.10E-03	2.20E-03	1.30E-04	5.50E-03	8.20E-08
Pu-238	1.10E+01	2.50E+01	2.20E-03	3.60E+01	5.40E-04
Pu-239	1.20E+01	2.80E+01	1.20E-03	4.00E+01	6.00E-04
Pu-240	1.20E+01	2.80E+01	2.20E-03	4.00E+01	6.00E-04
Pu-241	2.30E-01	5.20E-01	5.90E-05	7.50E-01	1.10E-05
Pu-242	1.10E+01	2.70E+01	1.80E-03	3.80E+01	5.70E-04
Ru-106	6.70E-02	2.20E-02	7.70E-01	8.60E-01	1.30E-05
Sb-125	8.40E-03	7.00E-04	1.90E+00	1.90E+00	2.80E-05
Se-79	2.90E-02	6.40E-04	0.00E+00	3.00E-02	4.50E-07
Sm-151	1.30E-03	1.90E-03	1.50E-05	3.30E-03	4.90E-08
Sr-90	4.80E-01	8.30E-02	1.40E-02	5.70E-01	8.60E-06
Tc-99	4.90E-03	5.40E-04	6.90E-04	6.20E-03	9.30E-08
Th-228	1.10E+00	1.90E+01	5.90E+00	2.60E+01	3.80E-04
Th-229	1.20E+01	1.40E+02	2.70E+00	1.50E+02	2.30E-03
Th-230	1.90E+00	2.10E+01	6.80E-03	2.30E+01	3.40E-04
Th-232	9.20E+00	1.10E+02	3.60E-03	1.20E+02	1.70E-03
U-232	4.40E+00	4.30E+01	4.50E-03	4.70E+01	7.00E-04
U-233	9.80E-01	8.80E+00	4.80E-03	9.80E+00	1.50E-04
U-234	9.60E-01	8.60E+00	2.40E-03	9.60E+00	1.40E-04
U-235	9.00E-01	8.00E+00	1.50E+00	1.00E+01	1.50E-04
U-238	8.60E-01	7.70E+00	2.40E-01	8.80E+00	1.30E-04
Zn-65	3.00E-02	8.20E-04	1.70E+00	1.70E+00	2.60E-05
Zr-93	5.60E-03	2.10E-02	0.00E+00	2.60E-02	4.00E-07

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.16 Baseline Worker Doses for a 2,000-h Initial Fabrication Coil Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	4.70E+01	4.30E+02	8.00E+00	4.80E+02	4.80E-04
Ag-110m	2.30E-02	3.30E-03	4.30E+01	4.30E+01	4.30E-05
Am-241	1.20E+01	2.90E+01	2.00E-01	4.10E+01	4.10E-05
Am-243	1.20E+01	2.90E+01	3.80E+00	4.50E+01	4.50E-05
Ca-41	4.30E-03	8.70E-05	0.00E+00	4.40E-03	4.40E-09
Ce-144	4.70E-02	1.60E-02	8.50E-01	9.20E-01	9.20E-07
Cl-36	1.00E-02	1.40E-03	9.60E-03	2.10E-02	2.10E-08
Cm-243	8.40E+00	2.00E+01	2.40E+00	3.00E+01	3.00E-05
Cm-244	6.70E+00	1.60E+01	6.30E-04	2.20E+01	2.20E-05
Cm-245	1.30E+01	3.00E+01	1.50E+00	4.40E+01	4.40E-05
Cm-246	1.30E+01	2.90E+01	6.20E-04	4.20E+01	4.20E-05
Cm-247	1.20E+01	2.70E+01	7.50E+00	4.60E+01	4.60E-05
Co-57	2.70E-03	3.90E-04	1.40E+00	1.40E+00	1.40E-06
Co-60	8.50E-02	1.30E-02	6.00E+01	6.00E+01	6.00E-05
Cs-134	2.10E-01	2.50E-03	3.20E+01	3.20E+01	3.20E-05
Cs-135	2.40E-02	3.00E-04	0.00E+00	2.40E-02	2.40E-08
Cs-137	1.70E-01	2.00E-03	1.30E+01	1.30E+01	1.30E-05
Eu-152	2.10E-02	1.40E-02	2.70E+01	2.70E+01	2.70E-05
Eu-154	3.10E-02	1.80E-02	2.90E+01	2.90E+01	2.90E-05
Fe-55	1.80E-03	1.50E-04	0.00E+00	2.00E-03	2.00E-09
Mn-54	6.40E-03	3.00E-04	1.40E+01	1.40E+01	1.40E-05
Na-22	3.40E-02	4.40E-04	4.70E+01	4.70E+01	4.70E-05
Nb-94	2.40E-02	2.70E-02	3.80E+01	3.80E+01	3.80E-05
Ni-59	7.10E-04	1.80E-04	0.00E+00	8.80E-04	8.80E-10
Ni-63	1.90E-03	4.10E-04	0.00E+00	2.40E-03	2.40E-09
Np-237	1.50E+01	3.50E+01	4.50E+00	5.50E+01	5.50E-05
Pb-210	1.80E+01	8.70E-01	1.10E-02	1.90E+01	1.90E-05
Pm-147	3.10E-03	2.20E-03	1.90E-04	5.50E-03	5.50E-09
Pu-238	1.10E+01	2.50E+01	7.50E-04	3.60E+01	3.60E-05
Pu-239	1.20E+01	2.80E+01	1.30E-03	4.00E+01	4.00E-05
Pu-240	1.20E+01	2.80E+01	7.30E-04	4.00E+01	4.00E-05
Pu-241	2.30E-01	5.20E-01	7.90E-05	7.50E-01	7.50E-07
Pu-242	1.10E+01	2.70E+01	6.30E-04	3.80E+01	3.80E-05
Ru-106	6.70E-02	2.20E-02	3.70E+00	3.80E+00	3.80E-06
Sb-125	8.40E-03	7.00E-04	8.60E+00	8.60E+00	8.60E-06
Se-79	2.90E-02	6.40E-04	0.00E+00	3.00E-02	3.00E-08
Sm-151	1.30E-03	1.90E-03	4.80E-06	3.20E-03	3.20E-09
Sr-90	4.80E-01	8.30E-02	9.20E-02	6.50E-01	6.50E-07
Tc-99	4.90E-03	5.40E-04	5.50E-04	6.00E-03	6.00E-09
Th-228	1.10E+00	1.90E+01	3.30E+01	5.30E+01	5.30E-05
Th-229	1.20E+01	1.40E+02	6.50E+00	1.60E+02	1.60E-04
Th-230	1.90E+00	2.10E+01	5.20E-03	2.30E+01	2.30E-05
Th-232	9.20E+00	1.10E+02	2.30E-03	1.20E+02	1.20E-04
U-232	4.40E+00	4.30E+01	3.90E-03	4.70E+01	4.70E-05
U-233	9.80E-01	8.80E+00	6.00E-03	9.80E+00	9.80E-06
U-234	9.60E-01	8.60E+00	1.80E-03	9.60E+00	9.60E-06
U-235	9.00E-01	8.00E+00	3.20E+00	1.20E+01	1.20E-05
U-238	8.60E-01	7.70E+00	5.30E-01	9.10E+00	9.10E-06
Zn-65	3.00E-02	8.20E-04	9.00E+00	9.10E+00	9.10E-06
Zr-93	5.60E-03	2.10E-02	0.00E+00	2.60E-02	2.60E-08

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.17 Baseline Worker Doses for a 2,000-h Final Fabrication Sheet Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	2.70E+00	2.70E+00	5.50E-05
Ag-110m	0.00E+00	0.00E+00	7.90E+00	7.90E+00	1.60E-04
Am-241	0.00E+00	0.00E+00	5.30E-01	5.30E-01	1.10E-05
Am-243	0.00E+00	0.00E+00	2.80E+00	2.80E+00	5.50E-05
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	2.50E-01	2.50E-01	4.90E-06
Cl-36	0.00E+00	0.00E+00	2.10E-03	2.10E-03	4.10E-08
Cm-243	0.00E+00	0.00E+00	1.10E+00	1.10E+00	2.30E-05
Cm-244	0.00E+00	0.00E+00	1.90E-03	1.90E-03	3.70E-08
Cm-245	0.00E+00	0.00E+00	1.10E+00	1.10E+00	2.20E-05
Cm-246	0.00E+00	0.00E+00	1.90E-03	1.90E-03	3.80E-08
Cm-247	0.00E+00	0.00E+00	1.90E+00	1.90E+00	3.80E-05
Co-57	0.00E+00	0.00E+00	9.50E-01	9.50E-01	1.90E-05
Co-60	0.00E+00	0.00E+00	1.00E+01	1.00E+01	2.00E-04
Cs-134	0.00E+00	0.00E+00	6.30E+00	6.30E+00	1.30E-04
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	2.70E+00	2.70E+00	5.30E-05
Eu-152	0.00E+00	0.00E+00	5.50E+00	5.50E+00	1.10E-04
Eu-154	0.00E+00	0.00E+00	5.80E+00	5.80E+00	1.20E-04
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	2.60E+00	2.60E+00	5.20E-05
Na-22	0.00E+00	0.00E+00	8.90E+00	8.90E+00	1.80E-04
Nb-94	0.00E+00	0.00E+00	7.20E+00	7.20E+00	1.40E-04
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	1.80E+00	1.80E+00	3.50E-05
Pb-210	0.00E+00	0.00E+00	3.20E-02	3.20E-02	6.40E-07
Pm-147	0.00E+00	0.00E+00	1.30E-04	1.30E-04	2.60E-09
Pu-238	0.00E+00	0.00E+00	2.20E-03	2.20E-03	4.40E-08
Pu-239	0.00E+00	0.00E+00	1.20E-03	1.20E-03	2.30E-08
Pu-240	0.00E+00	0.00E+00	2.20E-03	2.20E-03	4.30E-08
Pu-241	0.00E+00	0.00E+00	5.90E-05	5.90E-05	1.20E-09
Pu-242	0.00E+00	0.00E+00	1.80E-03	1.80E-03	3.70E-08
Ru-106	0.00E+00	0.00E+00	7.70E-01	7.70E-01	1.50E-05
Sb-125	0.00E+00	0.00E+00	1.90E+00	1.90E+00	3.70E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	1.50E-05	1.50E-05	2.90E-10
Sr-90	0.00E+00	0.00E+00	1.40E-02	1.40E-02	2.80E-07
Tc-99	0.00E+00	0.00E+00	6.90E-04	6.90E-04	1.40E-08
Th-228	0.00E+00	0.00E+00	5.90E+00	5.90E+00	1.20E-04
Th-229	0.00E+00	0.00E+00	2.70E+00	2.70E+00	5.30E-05
Th-230	0.00E+00	0.00E+00	6.80E-03	6.80E-03	1.40E-07
Th-232	0.00E+00	0.00E+00	3.60E-03	3.60E-03	7.10E-08
U-232	0.00E+00	0.00E+00	4.50E-03	4.50E-03	9.00E-08
U-233	0.00E+00	0.00E+00	4.80E-03	4.80E-03	9.50E-08
U-234	0.00E+00	0.00E+00	2.40E-03	2.40E-03	4.80E-08
U-235	0.00E+00	0.00E+00	1.50E+00	1.50E+00	2.90E-05
U-238	0.00E+00	0.00E+00	2.40E-01	2.40E-01	4.80E-06
Zn-65	0.00E+00	0.00E+00	1.70E+00	1.70E+00	3.40E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.18 Baseline Worker Doses for a 2,000-h Final Fabrication Coil Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	8.00E+00	8.00E+00	4.00E-05
Ag-110m	0.00E+00	0.00E+00	4.30E+01	4.30E+01	2.10E-04
Am-241	0.00E+00	0.00E+00	2.00E-01	2.00E-01	9.80E-07
Am-243	0.00E+00	0.00E+00	3.80E+00	3.80E+00	1.90E-05
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	8.50E-01	8.50E-01	4.30E-06
Cl-36	0.00E+00	0.00E+00	9.60E-03	9.60E-03	4.80E-08
Cm-243	0.00E+00	0.00E+00	2.40E+00	2.40E+00	1.20E-05
Cm-244	0.00E+00	0.00E+00	6.30E-04	6.30E-04	3.10E-09
Cm-245	0.00E+00	0.00E+00	1.50E+00	1.50E+00	7.30E-06
Cm-246	0.00E+00	0.00E+00	6.20E-04	6.20E-04	3.10E-09
Cm-247	0.00E+00	0.00E+00	7.50E+00	7.50E+00	3.70E-05
Co-57	0.00E+00	0.00E+00	1.40E+00	1.40E+00	7.20E-06
Co-60	0.00E+00	0.00E+00	6.00E+01	6.00E+01	3.00E-04
Cs-134	0.00E+00	0.00E+00	3.20E+01	3.20E+01	1.60E-04
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	1.30E+01	1.30E+01	6.60E-05
Eu-152	0.00E+00	0.00E+00	2.70E+01	2.70E+01	1.30E-04
Eu-154	0.00E+00	0.00E+00	2.90E+01	2.90E+01	1.50E-04
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	1.40E+01	1.40E+01	7.00E-05
Na-22	0.00E+00	0.00E+00	4.70E+01	4.70E+01	2.40E-04
Nb-94	0.00E+00	0.00E+00	3.80E+01	3.80E+01	1.90E-04
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	4.50E+00	4.50E+00	2.30E-05
Pb-210	0.00E+00	0.00E+00	1.10E-02	1.10E-02	5.50E-08
Pm-147	0.00E+00	0.00E+00	1.90E-04	1.90E-04	9.40E-10
Pu-238	0.00E+00	0.00E+00	7.50E-04	7.50E-04	3.70E-09
Pu-239	0.00E+00	0.00E+00	1.30E-03	1.30E-03	6.50E-09
Pu-240	0.00E+00	0.00E+00	7.30E-04	7.30E-04	3.60E-09
Pu-241	0.00E+00	0.00E+00	7.90E-05	7.90E-05	3.90E-10
Pu-242	0.00E+00	0.00E+00	6.30E-04	6.30E-04	3.10E-09
Ru-106	0.00E+00	0.00E+00	3.70E+00	3.70E+00	1.80E-05
Sb-125	0.00E+00	0.00E+00	8.60E+00	8.60E+00	4.30E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	4.80E-06	4.80E-06	2.40E-11
Sr-90	0.00E+00	0.00E+00	9.20E-02	9.20E-02	4.60E-07
Tc-99	0.00E+00	0.00E+00	5.50E-04	5.50E-04	2.80E-09
Th-228	0.00E+00	0.00E+00	3.30E+01	3.30E+01	1.70E-04
Th-229	0.00E+00	0.00E+00	6.50E+00	6.50E+00	3.30E-05
Th-230	0.00E+00	0.00E+00	5.20E-03	5.20E-03	2.60E-08
Th-232	0.00E+00	0.00E+00	2.30E-03	2.30E-03	1.20E-08
U-232	0.00E+00	0.00E+00	3.90E-03	3.90E-03	2.00E-08
U-233	0.00E+00	0.00E+00	6.00E-03	6.00E-03	3.00E-08
U-234	0.00E+00	0.00E+00	1.80E-03	1.80E-03	8.90E-09
U-235	0.00E+00	0.00E+00	3.20E+00	3.20E+00	1.60E-05
U-238	0.00E+00	0.00E+00	5.30E-01	5.30E-01	2.70E-06
Zn-65	0.00E+00	0.00E+00	9.00E+00	9.00E+00	4.50E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.19 Baseline Worker Doses for a 2,000-h Distribution Loader[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	6.00E+00	6.00E+00	1.20E-05
Ag-110m	0.00E+00	0.00E+00	3.20E+01	3.20E+01	6.40E-05
Am-241	0.00E+00	0.00E+00	1.40E-01	1.40E-01	2.80E-07
Am-243	0.00E+00	0.00E+00	2.80E+00	2.80E+00	5.50E-06
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	6.40E-01	6.40E-01	1.30E-06
Cl-36	0.00E+00	0.00E+00	7.20E-03	7.20E-03	1.40E-08
Cm-243	0.00E+00	0.00E+00	1.80E+00	1.80E+00	3.60E-06
Cm-244	0.00E+00	0.00E+00	3.30E-04	3.30E-04	6.60E-10
Cm-245	0.00E+00	0.00E+00	1.10E+00	1.10E+00	2.10E-06
Cm-246	0.00E+00	0.00E+00	2.90E-04	2.90E-04	5.80E-10
Cm-247	0.00E+00	0.00E+00	5.60E+00	5.60E+00	1.10E-05
Co-57	0.00E+00	0.00E+00	1.00E+00	1.00E+00	2.10E-06
Co-60	0.00E+00	0.00E+00	4.50E+01	4.50E+01	9.00E-05
Cs-134	0.00E+00	0.00E+00	2.40E+01	2.40E+01	4.80E-05
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	1.00E+01	1.00E+01	2.00E-05
Eu-152	0.00E+00	0.00E+00	2.00E+01	2.00E+01	4.10E-05
Eu-154	0.00E+00	0.00E+00	2.20E+01	2.20E+01	4.40E-05
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	1.00E+01	1.00E+01	2.10E-05
Na-22	0.00E+00	0.00E+00	3.60E+01	3.60E+01	7.10E-05
Nb-94	0.00E+00	0.00E+00	2.90E+01	2.90E+01	5.80E-05
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	3.40E+00	3.40E+00	6.70E-06
Pb-210	0.00E+00	0.00E+00	7.60E-03	7.60E-03	1.50E-08
Pm-147	0.00E+00	0.00E+00	1.40E-04	1.40E-04	2.70E-10
Pu-238	0.00E+00	0.00E+00	4.10E-04	4.10E-04	8.20E-10
Pu-239	0.00E+00	0.00E+00	9.20E-04	9.20E-04	1.80E-09
Pu-240	0.00E+00	0.00E+00	4.00E-04	4.00E-04	8.00E-10
Pu-241	0.00E+00	0.00E+00	5.80E-05	5.80E-05	1.20E-10
Pu-242	0.00E+00	0.00E+00	3.50E-04	3.50E-04	7.10E-10
Ru-106	0.00E+00	0.00E+00	2.80E+00	2.80E+00	5.60E-06
Sb-125	0.00E+00	0.00E+00	6.50E+00	6.50E+00	1.30E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	2.80E-06	2.80E-06	5.70E-12
Sr-90	0.00E+00	0.00E+00	7.00E-02	7.00E-02	1.40E-07
Tc-99	0.00E+00	0.00E+00	4.00E-04	4.00E-04	7.90E-10
Th-228	0.00E+00	0.00E+00	2.50E+01	2.50E+01	5.10E-05
Th-229	0.00E+00	0.00E+00	4.80E+00	4.80E+00	9.70E-06
Th-230	0.00E+00	0.00E+00	3.80E-03	3.80E-03	7.50E-09
Th-232	0.00E+00	0.00E+00	1.60E-03	1.60E-03	3.20E-09
U-232	0.00E+00	0.00E+00	2.80E-03	2.80E-03	5.60E-09
U-233	0.00E+00	0.00E+00	4.40E-03	4.40E-03	8.80E-09
U-234	0.00E+00	0.00E+00	1.20E-03	1.20E-03	2.50E-09
U-235	0.00E+00	0.00E+00	2.30E+00	2.30E+00	4.70E-06
U-238	0.00E+00	0.00E+00	4.00E-01	4.00E-01	7.90E-07
Zn-65	0.00E+00	0.00E+00	6.80E+00	6.80E+00	1.40E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.20 Baseline Worker Doses for a 2,000-h Distribution Truck Driver[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	5.30E+00	5.30E+00	2.60E-05
Ag-110m	0.00E+00	0.00E+00	2.80E+01	2.80E+01	1.40E-04
Am-241	0.00E+00	0.00E+00	1.30E-01	1.30E-01	6.40E-07
Am-243	0.00E+00	0.00E+00	2.50E+00	2.50E+00	1.20E-05
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	5.70E-01	5.70E-01	2.80E-06
Cl-36	0.00E+00	0.00E+00	6.30E-03	6.30E-03	3.20E-08
Cm-243	0.00E+00	0.00E+00	1.60E+00	1.60E+00	8.00E-06
Cm-244	0.00E+00	0.00E+00	3.90E-04	3.90E-04	1.90E-09
Cm-245	0.00E+00	0.00E+00	9.60E-01	9.60E-01	4.80E-06
Cm-246	0.00E+00	0.00E+00	3.70E-04	3.70E-04	1.90E-09
Cm-247	0.00E+00	0.00E+00	4.90E+00	4.90E+00	2.50E-05
Co-57	0.00E+00	0.00E+00	9.50E-01	9.50E-01	4.70E-06
Co-60	0.00E+00	0.00E+00	4.00E+01	4.00E+01	2.00E-04
Cs-134	0.00E+00	0.00E+00	2.10E+01	2.10E+01	1.10E-04
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	8.80E+00	8.80E+00	4.40E-05
Eu-152	0.00E+00	0.00E+00	1.80E+01	1.80E+01	8.90E-05
Eu-154	0.00E+00	0.00E+00	1.90E+01	1.90E+01	9.70E-05
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	9.30E+00	9.30E+00	4.60E-05
Na-22	0.00E+00	0.00E+00	3.20E+01	3.20E+01	1.60E-04
Nb-94	0.00E+00	0.00E+00	2.50E+01	2.50E+01	1.30E-04
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	3.00E+00	3.00E+00	1.50E-05
Pb-210	0.00E+00	0.00E+00	7.10E-03	7.10E-03	3.60E-08
Pm-147	0.00E+00	0.00E+00	1.20E-04	1.20E-04	6.20E-10
Pu-238	0.00E+00	0.00E+00	4.70E-04	4.70E-04	2.30E-09
Pu-239	0.00E+00	0.00E+00	8.50E-04	8.50E-04	4.20E-09
Pu-240	0.00E+00	0.00E+00	4.50E-04	4.50E-04	2.30E-09
Pu-241	0.00E+00	0.00E+00	5.20E-05	5.20E-05	2.60E-10
Pu-242	0.00E+00	0.00E+00	3.90E-04	3.90E-04	2.00E-09
Ru-106	0.00E+00	0.00E+00	2.50E+00	2.50E+00	1.20E-05
Sb-125	0.00E+00	0.00E+00	5.70E+00	5.70E+00	2.90E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	3.10E-06	3.10E-06	1.50E-11
Sr-90	0.00E+00	0.00E+00	6.10E-02	6.10E-02	3.00E-07
Tc-99	0.00E+00	0.00E+00	3.60E-04	3.60E-04	1.80E-09
Th-228	0.00E+00	0.00E+00	2.20E+01	2.20E+01	1.10E-04
Th-229	0.00E+00	0.00E+00	4.30E+00	4.30E+00	2.20E-05
Th-230	0.00E+00	0.00E+00	3.40E-03	3.40E-03	1.70E-08
Th-232	0.00E+00	0.00E+00	1.50E-03	1.50E-03	7.50E-09
U-232	0.00E+00	0.00E+00	2.60E-03	2.60E-03	1.30E-08
U-233	0.00E+00	0.00E+00	4.00E-03	4.00E-03	2.00E-08
U-234	0.00E+00	0.00E+00	1.20E-03	1.20E-03	5.80E-09
U-235	0.00E+00	0.00E+00	2.10E+00	2.10E+00	1.10E-05
U-238	0.00E+00	0.00E+00	3.50E-01	3.50E-01	1.80E-06
Zn-65	0.00E+00	0.00E+00	6.00E+00	6.00E+00	3.00E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.21 Baseline Worker Doses for a 2,000-h Distribution Sheet Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	2.70E+00	2.70E+00	5.50E-05
Ag-110m	0.00E+00	0.00E+00	7.90E+00	7.90E+00	1.60E-04
Am-241	0.00E+00	0.00E+00	5.30E-01	5.30E-01	1.10E-05
Am-243	0.00E+00	0.00E+00	2.80E+00	2.80E+00	5.50E-05
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	2.50E-01	2.50E-01	4.90E-06
Cl-36	0.00E+00	0.00E+00	2.10E-03	2.10E-03	4.10E-08
Cm-243	0.00E+00	0.00E+00	1.10E+00	1.10E+00	2.30E-05
Cm-244	0.00E+00	0.00E+00	1.90E-03	1.90E-03	3.70E-08
Cm-245	0.00E+00	0.00E+00	1.10E+00	1.10E+00	2.20E-05
Cm-246	0.00E+00	0.00E+00	1.90E-03	1.90E-03	3.80E-08
Cm-247	0.00E+00	0.00E+00	1.90E+00	1.90E+00	3.80E-05
Co-57	0.00E+00	0.00E+00	9.50E-01	9.50E-01	1.90E-05
Co-60	0.00E+00	0.00E+00	1.00E+01	1.00E+01	2.00E-04
Cs-134	0.00E+00	0.00E+00	6.30E+00	6.30E+00	1.30E-04
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	2.70E+00	2.70E+00	5.30E-05
Eu-152	0.00E+00	0.00E+00	5.50E+00	5.50E+00	1.10E-04
Eu-154	0.00E+00	0.00E+00	5.80E+00	5.80E+00	1.20E-04
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	2.60E+00	2.60E+00	5.20E-05
Na-22	0.00E+00	0.00E+00	8.90E+00	8.90E+00	1.80E-04
Nb-94	0.00E+00	0.00E+00	7.20E+00	7.20E+00	1.40E-04
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	1.80E+00	1.80E+00	3.50E-05
Pb-210	0.00E+00	0.00E+00	3.20E-02	3.20E-02	6.40E-07
Pm-147	0.00E+00	0.00E+00	1.30E-04	1.30E-04	2.60E-09
Pu-238	0.00E+00	0.00E+00	2.20E-03	2.20E-03	4.40E-08
Pu-239	0.00E+00	0.00E+00	1.20E-03	1.20E-03	2.30E-08
Pu-240	0.00E+00	0.00E+00	2.20E-03	2.20E-03	4.30E-08
Pu-241	0.00E+00	0.00E+00	5.90E-05	5.90E-05	1.20E-09
Pu-242	0.00E+00	0.00E+00	1.80E-03	1.80E-03	3.70E-08
Ru-106	0.00E+00	0.00E+00	7.70E-01	7.70E-01	1.50E-05
Sb-125	0.00E+00	0.00E+00	1.90E+00	1.90E+00	3.70E-05
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	1.50E-05	1.50E-05	2.90E-10
Sr-90	0.00E+00	0.00E+00	1.40E-02	1.40E-02	2.80E-07
Tc-99	0.00E+00	0.00E+00	6.90E-04	6.90E-04	1.40E-08
Th-228	0.00E+00	0.00E+00	5.90E+00	5.90E+00	1.20E-04
Th-229	0.00E+00	0.00E+00	2.70E+00	2.70E+00	5.30E-05
Th-230	0.00E+00	0.00E+00	6.80E-03	6.80E-03	1.40E-07
Th-232	0.00E+00	0.00E+00	3.60E-03	3.60E-03	7.10E-08
U-232	0.00E+00	0.00E+00	4.50E-03	4.50E-03	9.00E-08
U-233	0.00E+00	0.00E+00	4.80E-03	4.80E-03	9.50E-08
U-234	0.00E+00	0.00E+00	2.40E-03	2.40E-03	4.80E-08
U-235	0.00E+00	0.00E+00	1.50E+00	1.50E+00	2.90E-05
U-238	0.00E+00	0.00E+00	2.40E-01	2.40E-01	4.80E-06
Zn-65	0.00E+00	0.00E+00	1.70E+00	1.70E+00	3.40E-05
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.22 Baseline Worker Doses for a 2,000-h Distribution Warehouse Worker[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	0.00E+00	0.00E+00	6.50E-01	6.50E-01	3.20E-06
Ag-110m	0.00E+00	0.00E+00	2.20E+00	2.20E+00	1.10E-05
Am-241	0.00E+00	0.00E+00	3.10E-02	3.10E-02	1.60E-07
Am-243	0.00E+00	0.00E+00	4.50E-01	4.50E-01	2.20E-06
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00	5.70E-02	5.70E-02	2.90E-07
Cl-36	0.00E+00	0.00E+00	5.90E-04	5.90E-04	3.00E-09
Cm-243	0.00E+00	0.00E+00	2.60E-01	2.60E-01	1.30E-06
Cm-244	0.00E+00	0.00E+00	6.40E-05	6.40E-05	3.20E-10
Cm-245	0.00E+00	0.00E+00	2.10E-01	2.10E-01	1.00E-06
Cm-246	0.00E+00	0.00E+00	5.20E-05	5.20E-05	2.60E-10
Cm-247	0.00E+00	0.00E+00	5.10E-01	5.10E-01	2.60E-06
Co-57	0.00E+00	0.00E+00	2.00E-01	2.00E-01	1.00E-06
Co-60	0.00E+00	0.00E+00	2.80E+00	2.80E+00	1.40E-05
Cs-134	0.00E+00	0.00E+00	1.80E+00	1.80E+00	8.90E-06
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	7.70E-01	7.70E-01	3.80E-06
Eu-152	0.00E+00	0.00E+00	1.50E+00	1.50E+00	7.30E-06
Eu-154	0.00E+00	0.00E+00	1.50E+00	1.50E+00	7.70E-06
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00	7.20E-01	7.20E-01	3.60E-06
Na-22	0.00E+00	0.00E+00	2.50E+00	2.50E+00	1.20E-05
Nb-94	0.00E+00	0.00E+00	2.00E+00	2.00E+00	1.00E-05
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	0.00E+00	0.00E+00	4.00E-01	4.00E-01	2.00E-06
Pb-210	0.00E+00	0.00E+00	1.70E-03	1.70E-03	8.60E-09
Pm-147	0.00E+00	0.00E+00	2.70E-05	2.70E-05	1.40E-10
Pu-238	0.00E+00	0.00E+00	8.30E-05	8.30E-05	4.20E-10
Pu-239	0.00E+00	0.00E+00	1.90E-04	1.90E-04	9.50E-10
Pu-240	0.00E+00	0.00E+00	8.30E-05	8.30E-05	4.10E-10
Pu-241	0.00E+00	0.00E+00	1.00E-05	1.00E-05	5.20E-11
Pu-242	0.00E+00	0.00E+00	7.40E-05	7.40E-05	3.70E-10
Ru-106	0.00E+00	0.00E+00	2.20E-01	2.20E-01	1.10E-06
Sb-125	0.00E+00	0.00E+00	5.40E-01	5.40E-01	2.70E-06
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	0.00E+00	0.00E+00	5.80E-07	5.80E-07	2.90E-12
Sr-90	0.00E+00	0.00E+00	3.90E-03	3.90E-03	2.00E-08
Tc-99	0.00E+00	0.00E+00	9.00E-05	9.00E-05	4.50E-10
Th-228	0.00E+00	0.00E+00	1.60E+00	1.60E+00	8.10E-06
Th-229	0.00E+00	0.00E+00	5.40E-01	5.40E-01	2.70E-06
Th-230	0.00E+00	0.00E+00	7.10E-04	7.10E-04	3.50E-09
Th-232	0.00E+00	0.00E+00	3.30E-04	3.30E-04	1.70E-09
U-232	0.00E+00	0.00E+00	5.20E-04	5.20E-04	2.60E-09
U-233	0.00E+00	0.00E+00	9.10E-04	9.10E-04	4.50E-09
U-234	0.00E+00	0.00E+00	2.50E-04	2.50E-04	1.30E-09
U-235	0.00E+00	0.00E+00	3.50E-01	3.50E-01	1.80E-06
U-238	0.00E+00	0.00E+00	4.10E-02	4.10E-02	2.00E-07
Zn-65	0.00E+00	0.00E+00	4.60E-01	4.60E-01	2.30E-06
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.23 Baseline Public Doses for Tool Reuse[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	1.30E+02	5.70E+02	7.30E-01	7.10E+02	7.10E-04
Ag-110m	6.10E-02	4.40E-03	3.10E+00	3.20E+00	3.20E-06
Am-241	3.30E+01	3.80E+01	8.90E-02	7.10E+01	7.10E-05
Am-243	3.30E+01	3.80E+01	5.00E-01	7.10E+01	7.10E-05
Ca-41	1.10E-02	1.20E-04	0.00E+00	1.20E-02	1.20E-08
Ce-144	1.30E-01	2.10E-02	7.90E-02	2.30E-01	2.30E-07
Cl-36	2.70E-02	1.90E-03	1.30E-03	3.00E-02	3.00E-08
Cm-243	2.20E+01	2.60E+01	2.60E-01	4.90E+01	4.90E-05
Cm-244	1.80E+01	2.10E+01	5.90E-03	3.90E+01	3.90E-05
Cm-245	3.40E+01	3.90E+01	2.10E-01	7.30E+01	7.30E-05
Cm-246	3.30E+01	3.90E+01	5.40E-03	7.20E+01	7.20E-05
Cm-247	3.10E+01	3.60E+01	6.10E-01	6.70E+01	6.70E-05
Co-57	7.10E-03	5.20E-04	1.80E-01	1.80E-01	1.80E-07
Co-60	2.30E-01	1.80E-02	4.10E+00	4.30E+00	4.30E-06
Cs-134	5.60E-01	3.40E-03	2.40E+00	2.90E+00	2.90E-06
Cs-135	6.40E-02	3.90E-04	0.00E+00	6.40E-02	6.40E-08
Cs-137	4.50E-01	2.70E-03	1.00E+00	1.50E+00	1.50E-06
Eu-152	5.70E-02	1.90E-02	2.00E+00	2.10E+00	2.10E-06
Eu-154	8.30E-02	2.40E-02	2.10E+00	2.30E+00	2.30E-06
Fe-55	4.80E-03	2.00E-04	0.00E+00	5.00E-03	5.00E-09
Mn-54	1.70E-02	4.00E-04	1.00E+00	1.00E+00	1.00E-06
Na-22	9.10E-02	5.80E-04	3.40E+00	3.50E+00	3.50E-06
Nb-94	6.40E-02	3.60E-02	2.80E+00	2.90E+00	2.90E-06
Ni-59	1.90E-03	2.30E-04	0.00E+00	2.10E-03	2.10E-09
Ni-63	5.20E-03	5.40E-04	0.00E+00	5.70E-03	5.70E-09
Np-237	4.00E+01	4.70E+01	4.60E-01	8.70E+01	8.70E-05
Pb-210	4.80E+01	1.20E+00	9.70E-03	4.90E+01	4.90E-05
Pm-147	8.30E-03	3.00E-03	6.80E-05	1.10E-02	1.10E-08
Pu-238	2.90E+01	3.40E+01	6.50E-03	6.30E+01	6.30E-05
Pu-239	3.20E+01	3.70E+01	2.40E-03	6.90E+01	6.90E-05
Pu-240	3.20E+01	3.70E+01	6.20E-03	6.90E+01	6.90E-05
Pu-241	6.00E-01	7.00E-01	1.30E-05	1.30E+00	1.30E-06
Pu-242	3.00E+01	3.60E+01	5.10E-03	6.60E+01	6.60E-05
Ru-106	1.80E-01	3.00E-02	2.80E-01	4.90E-01	4.90E-07
Sb-125	2.20E-02	9.30E-04	7.20E-01	7.50E-01	7.50E-07
Se-79	7.80E-02	8.50E-04	0.00E+00	7.90E-02	7.90E-08
Sm-151	3.50E-03	2.60E-03	2.80E-05	6.10E-03	6.10E-09
Sr-90	1.40E+00	1.10E-01	9.80E-03	1.50E+00	1.50E-06
Tc-99	1.30E-02	7.20E-04	2.00E-04	1.40E-02	1.40E-08
Th-228	3.00E+00	2.50E+01	2.20E+00	3.00E+01	3.00E-05
Th-229	3.20E+01	1.90E+02	6.70E-01	2.20E+02	2.20E-04
Th-230	4.90E+00	2.80E+01	3.60E-03	3.30E+01	3.30E-05
Th-232	2.50E+01	1.40E+02	3.40E-03	1.70E+02	1.70E-04
U-232	1.20E+01	5.70E+01	6.30E-03	6.80E+01	6.80E-05
U-233	2.60E+00	1.20E+01	3.20E-03	1.40E+01	1.40E-05
U-234	2.60E+00	1.10E+01	5.30E-03	1.40E+01	1.40E-05
U-235	2.40E+00	1.10E+01	3.70E-01	1.30E+01	1.30E-05
U-238	2.30E+00	1.00E+01	6.20E-02	1.30E+01	1.30E-05
Zn-65	8.10E-02	1.10E-03	6.40E-01	7.20E-01	7.20E-07
Zr-93	1.50E-02	2.80E-02	0.00E+00	4.30E-02	4.30E-08

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.24 Baseline Public Doses for Building Occupancy Scenario[a]

Nuclide	Ingestion (μSv/yr)	Inhalation (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	8.00E+03	3.40E+04	7.20E+00	4.20E+04	1.70E-01
Ag-110m	3.70E+00	2.60E-01	4.70E+01	5.10E+01	2.00E-04
Am-241	2.00E+03	2.30E+03	4.80E-01	4.30E+03	1.70E-02
Am-243	2.00E+03	2.30E+03	6.60E+00	4.20E+03	1.70E-02
Ca-41	6.90E-01	7.00E-03	0.00E+00	6.90E-01	2.80E-06
Ce-144	7.50E+00	1.30E+00	1.10E+00	9.90E+00	4.00E-05
Cl-36	1.60E+00	1.10E-01	1.90E-02	1.80E+00	7.10E-06
Cm-243	1.30E+03	1.60E+03	3.70E+00	2.90E+03	1.20E-02
Cm-244	1.10E+03	1.30E+03	6.60E-02	2.30E+03	9.30E-03
Cm-245	2.00E+03	2.40E+03	2.70E+00	4.40E+03	1.80E-02
Cm-246	2.00E+03	2.30E+03	6.00E-02	4.30E+03	1.70E-02
Cm-247	1.80E+03	2.20E+03	9.50E+00	4.00E+03	1.60E-02
Co-57	4.30E-01	3.10E-02	2.30E+00	2.70E+00	1.10E-05
Co-60	1.40E+01	1.10E+00	4.20E+01	5.70E+01	2.30E-04
Cs-134	3.40E+01	2.00E-01	3.60E+01	7.00E+01	2.80E-04
Cs-135	3.80E+00	2.40E-02	0.00E+00	3.80E+00	1.50E-05
Cs-137	2.70E+01	1.60E-01	1.00E+01	3.70E+01	1.50E-04
Eu-152	3.40E+00	1.10E+00	3.00E+01	3.50E+01	1.40E-04
Eu-154	5.00E+00	1.40E+00	3.20E+01	3.80E+01	1.50E-04
Fe-55	2.90E-01	1.20E-02	0.00E+00	3.00E-01	1.20E-06
Mn-54	1.00E+00	2.40E-02	1.60E+01	1.70E+01	6.70E-05
Na-22	5.40E+00	3.50E-02	5.20E+01	5.70E+01	2.30E-04
Nb-94	3.90E+00	2.20E+00	4.30E+01	4.90E+01	2.00E-04
Ni-59	1.10E-01	1.40E-02	0.00E+00	1.30E-01	5.10E-07
Ni-63	3.10E-01	3.30E-02	0.00E+00	3.40E-01	1.40E-06
Np-237	2.40E+03	2.80E+03	6.70E+00	5.20E+03	2.10E-02
Pb-210	2.90E+03	6.90E+01	1.10E-01	2.90E+03	1.20E-02
Pm-147	5.00E-01	1.80E-01	8.70E-04	6.80E-01	2.70E-06
Pu-238	1.70E+03	2.00E+03	6.50E-02	3.80E+03	1.50E-02
Pu-239	1.90E+03	2.20E+03	2.50E-02	4.10E+03	1.70E-02
Pu-240	1.90E+03	2.20E+03	6.30E-02	4.10E+03	1.70E-02
Pu-241	3.60E+01	4.20E+01	1.70E-04	7.80E+01	3.10E-04
Pu-242	1.80E+03	2.10E+03	5.20E-02	3.90E+03	1.60E-02
Ru-106	1.10E+01	1.80E+00	4.30E+00	1.70E+01	6.70E-05
Sb-125	1.30E+00	5.60E-02	1.10E+01	1.30E+01	5.00E-05
Se-79	4.70E+00	5.10E-02	0.00E+00	4.80E+00	1.90E-05
Sm-151	2.10E-01	1.50E-01	3.10E-04	3.60E-01	1.50E-06
Sr-90	8.30E+01	6.70E+00	9.50E-02	9.00E+01	3.60E-04
Tc-99	7.90E-01	4.30E-02	1.50E-03	8.30E-01	3.30E-06
Th-228	1.80E+02	1.50E+03	3.20E+01	1.70E+03	6.80E-03
Th-229	1.90E+03	1.10E+04	9.40E+00	1.30E+04	5.20E-02
Th-230	3.00E+02	1.70E+03	3.60E-02	2.00E+03	7.90E-03
Th-232	1.50E+03	8.50E+03	3.30E-02	1.00E+04	4.00E-02
U-232	7.00E+02	3.40E+03	6.30E-02	4.10E+03	1.60E-02
U-233	1.60E+02	7.00E+02	3.40E-02	8.60E+02	3.40E-03
U-234	1.50E+02	6.90E+02	5.20E-02	8.40E+02	3.40E-03
U-235	1.40E+02	6.40E+02	5.00E+00	7.90E+02	3.10E-03
U-238	1.40E+02	6.10E+02	5.40E-01	7.50E+02	3.00E-03
Zn-65	4.90E+00	6.60E-02	6.30E+00	1.10E+01	4.30E-05
Zr-93	9.00E-01	1.70E+00	0.00E+00	2.60E+00	1.00E-05

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

TABLE D.25 Baseline Public Doses for a 100-t Batch — Parking Lot Scenario and Room/Office Scenario[a]

	Parking Lot Scenario		Room/Office Scenario	
Nuclide	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	3.50E-01	3.70E-04	9.20E+00	1.30E-03
Ag-110m	1.70E+00	1.80E-03	2.70E+01	3.90E-03
Am-241	8.30E-03	8.70E-06	1.60E+00	2.30E-04
Am-243	1.70E-01	1.70E-04	8.90E+00	1.30E-03
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	3.40E-02	3.60E-05	8.20E-01	1.20E-04
Cl-36	4.20E-04	4.40E-07	7.10E-03	1.00E-06
Cm-243	1.10E-01	1.10E-04	3.80E+00	5.50E-04
Cm-244	2.40E-05	2.50E-08	4.80E-03	6.90E-07
Cm-245	6.40E-02	6.80E-05	3.60E+00	5.20E-04
Cm-246	2.20E-05	2.30E-08	4.70E-03	6.80E-07
Cm-247	3.20E-01	3.40E-04	6.50E+00	9.30E-04
Co-57	6.40E-02	6.70E-05	3.20E+00	4.50E-04
Co-60	2.30E+00	2.50E-03	3.50E+01	5.00E-03
Cs-134	1.30E+00	1.40E-03	2.10E+01	3.10E-03
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	5.70E-01	6.00E-04	9.10E+00	1.30E-03
Eu-152	1.10E+00	1.20E-03	1.90E+01	2.70E-03
Eu-154	1.20E+00	1.30E-03	2.00E+01	2.90E-03
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	5.70E-01	6.00E-04	8.80E+00	1.30E-03
Na-22	1.90E+00	2.00E-03	3.10E+01	4.40E-03
Nb-94	1.60E+00	1.70E-03	2.50E+01	3.60E-03
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	2.00E-01	2.10E-04	5.90E+00	8.40E-04
Pb-210	4.60E-04	4.80E-07	9.40E-02	1.30E-05
Pm-147	8.40E-06	8.80E-09	4.30E-04	6.30E-08
Pu-238	2.90E-05	3.00E-08	5.80E-03	8.30E-07
Pu-239	5.60E-05	5.90E-08	3.60E-03	5.20E-07
Pu-240	2.80E-05	3.00E-08	5.70E-03	8.20E-07
Pu-241	3.50E-06	3.60E-09	1.90E-04	2.80E-08
Pu-242	2.40E-05	2.60E-08	4.90E-03	7.00E-07
Ru-106	1.60E-01	1.70E-04	2.60E+00	3.80E-04
Sb-125	3.70E-01	3.90E-04	6.40E+00	9.20E-04
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	1.90E-07	2.00E-10	4.00E-05	5.70E-09
Sr-90	3.50E-03	3.70E-06	4.80E-02	6.90E-06
Tc-99	2.40E-05	2.50E-08	2.20E-03	3.20E-07
Th-228	1.30E+00	1.40E-03	2.00E+01	2.90E-03
Th-229	2.80E-01	2.90E-04	8.70E+00	1.30E-03
Th-230	2.30E-04	2.40E-07	2.10E-02	3.00E-06
Th-232	9.90E-05	1.00E-07	1.10E-02	1.50E-06
U-232	1.70E-04	1.80E-07	1.40E-02	2.00E-06
U-233	2.70E-04	2.80E-07	1.60E-02	2.20E-06
U-234	7.70E-05	8.00E-08	7.20E-03	1.00E-06
U-235	1.40E-01	1.50E-04	4.90E+00	7.10E-04
U-238	2.30E-02	2.40E-05	7.70E-01	1.10E-04
Zn-65	3.80E-01	4.00E-04	5.80E+00	8.30E-04
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

[b] Ingestion and inhalation doses do not apply for these scenarios.

TABLE D.26 Baseline Public Doses for a 100-t Batch — Appliance Scenario and Automobile Scenario[a]

	Appliance Scenario		Automobile Scenario	
Nuclide	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	2.90E-01	1.00E-04	3.50E+00	8.80E-04
Ag-110m	7.80E-01	2.70E-04	9.50E+00	2.40E-03
Am-241	8.50E-02	2.90E-05	9.10E-01	2.30E-04
Am-243	3.10E-01	1.10E-04	3.70E+00	9.20E-04
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	2.70E-02	9.30E-06	3.20E-01	8.00E-05
Cl-36	2.10E-04	7.10E-08	2.50E-03	6.40E-07
Cm-243	1.20E-01	4.10E-05	1.50E+00	3.70E-04
Cm-244	4.00E-04	1.40E-07	4.10E-03	1.00E-06
Cm-245	1.20E-01	4.10E-05	1.40E+00	3.60E-04
Cm-246	4.40E-04	1.50E-07	4.50E-03	1.10E-06
Cm-247	1.90E-01	6.70E-05	2.30E+00	5.90E-04
Co-57	9.80E-02	3.30E-05	1.20E+00	3.00E-04
Co-60	1.00E+00	3.50E-04	1.20E+01	3.10E-03
Cs-134	6.20E-01	2.10E-04	7.60E+00	1.90E-03
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	2.70E-01	9.10E-05	3.20E+00	8.10E-04
Eu-152	5.70E-01	2.00E-04	6.90E+00	1.70E-03
Eu-154	5.90E-01	2.00E-04	7.10E+00	1.80E-03
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	2.60E-01	8.90E-05	3.10E+00	7.90E-04
Na-22	8.90E-01	3.00E-04	1.10E+01	2.70E-03
Nb-94	7.10E-01	2.40E-04	8.70E+00	2.20E-03
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	1.90E-01	6.40E-05	2.30E+00	5.70E-04
Pb-210	6.60E-03	2.20E-06	6.60E-02	1.70E-05
Pm-147	1.40E-05	4.60E-09	1.60E-04	4.10E-08
Pu-238	4.50E-04	1.60E-07	4.80E-03	1.20E-06
Pu-239	1.50E-04	5.00E-08	1.70E-03	4.30E-07
Pu-240	4.40E-04	1.50E-07	4.60E-03	1.20E-06
Pu-241	7.00E-06	2.40E-09	8.20E-05	2.10E-08
Pu-242	3.60E-04	1.20E-07	3.80E-03	9.70E-07
Ru-106	7.60E-02	2.60E-05	9.30E-01	2.30E-04
Sb-125	1.90E-01	6.60E-05	2.30E+00	5.90E-04
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	3.40E-06	1.20E-09	3.40E-05	8.60E-09
Sr-90	1.40E-03	4.70E-07	1.70E-02	4.20E-06
Tc-99	8.00E-05	2.80E-08	9.40E-04	2.40E-07
Th-228	5.90E-01	2.00E-04	7.10E+00	1.80E-03
Th-229	3.00E-01	1.00E-04	3.50E+00	8.90E-04
Th-230	8.80E-04	3.00E-07	1.00E-02	2.50E-06
Th-232	5.40E-04	1.90E-07	5.90E-03	1.50E-06
U-232	6.70E-04	2.30E-07	7.40E-03	1.90E-06
U-233	5.30E-04	1.80E-07	6.30E-03	1.60E-06
U-234	3.90E-04	1.30E-07	4.20E-03	1.10E-06
U-235	1.50E-01	5.20E-05	1.80E+00	4.60E-04
U-238	2.80E-02	9.60E-06	3.30E-01	8.20E-05
Zn-65	1.70E-01	5.80E-05	2.00E+00	5.20E-04
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

[b] Ingestion and inhalation doses do not apply for these scenarios.

TABLE D.27 Baseline Public Doses for a 100-t Batch — Office Furniture Scenario and Home Furniture Scenario[a]

	Office Furniture Scenario		Home Furniture Scenario	
Nuclide	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	1.10E+02	6.10E-04	8.60E+00	4.20E-03
Ag-110m	3.40E+02	1.90E-03	2.50E+01	1.20E-02
Am-241	1.50E+01	8.10E-05	1.80E+00	8.50E-04
Am-243	1.10E+00	5.90E-04	8.50E+00	4.10E-03
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	1.00E-01	5.60E-05	7.70E-01	3.70E-04
Cl-36	8.70E-04	4.80E-07	6.60E-03	3.20E-06
Cm-243	4.70E-01	2.60E-04	3.70E+00	1.80E-03
Cm-244	5.60E-04	3.10E-07	8.00E-03	3.80E-06
Cm-245	4.50E-01	2.50E-04	3.50E+00	1.70E-03
Cm-246	5.80E-04	3.20E-07	8.60E-03	4.10E-06
Cm-247	7.90E-01	4.40E-04	6.00E+00	2.90E-03
Co-57	3.90E-01	2.20E-04	3.00E+00	1.40E-03
Co-60	4.40E+00	2.50E-03	3.20E+01	1.50E-02
Cs-134	2.70E+00	1.50E-03	2.00E+01	9.40E-03
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	1.10E+00	6.40E-04	8.40E+00	4.00E-03
Eu-152	2.30E+00	1.30E-03	1.70E+01	8.30E-03
Eu-154	2.50E+00	1.40E-03	1.80E+01	8.80E-03
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	1.10E+00	6.20E-04	8.20E+00	3.90E-03
Na-22	3.80E+00	2.10E-03	2.80E+01	1.30E-02
Nb-94	3.10E+00	1.70E-03	2.30E+01	1.10E-02
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	7.10E-01	3.90E-04	5.60E+00	2.70E-03
Pb-210	8.40E-03	4.60E-06	1.20E-01	5.70E-05
Pm-147	5.30E-05	3.00E-08	4.10E-04	2.00E-07
Pu-238	6.70E-04	3.70E-07	9.30E-03	4.50E-06
Pu-239	4.60E-04	2.60E-07	4.00E-03	1.90E-06
Pu-240	6.40E-04	3.60E-07	9.00E-03	4.30E-06
Pu-241	2.30E-05	1.30E-08	1.90E-04	9.10E-08
Pu-242	5.50E-04	3.00E-07	7.50E-03	3.60E-06
Ru-106	3.20E-01	1.80E-04	2.40E+00	1.20E-03
Sb-125	7.80E-01	4.30E-04	6.00E+00	2.90E-03
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	4.10E-06	2.30E-09	6.20E-05	3.00E-08
Sr-90	6.10E-04	3.40E-07	4.30E-02	2.10E-05
Tc-99	2.70E-04	1.50E-08	2.20E-03	1.00E-06
Th-228	2.50E+00	1.40E-03	1.80E+01	8.80E-03
Th-229	1.10E+00	5.80E-04	8.40E+00	4.00E-03
Th-230	2.20E-03	1.20E-06	2.10E-02	1.00E-05
Th-232	1.10E-03	6.10E-07	1.20E-02	5.80E-06
U-232	1.50E-03	8.10E-07	1.50E-02	7.40E-06
U-233	2.00E-03	1.10E-05	5.00E-01	7.40E-06
U-234	7.90E-04	4.40E-08	7.00E-02	4.20E-06
U-235	6.00E-01	3.30E-05	6.00E+01	2.20E-03
U-238	9.20E-02	5.10E-06	5.00E+00	3.60E-04
Zn-65	7.40E-01	4.10E-05	3.00E+01	2.50E-03
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

[b] Ingestion and inhalation doses do not apply for these scenarios.

TABLE D.28 Baseline Public Doses for a 100-t Batch — Frying Pan Scenario[a,b]

Nuclide	Ingestion (μSv/yr)	External (μSv/yr)	Total Dose (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	2.20E+00	8.80E-01	3.10E+00	1.00E-02
Ag-110m	1.10E-03	2.50E+00	2.50E+00	8.20E-03
Am-241	5.80E-01	1.80E-01	7.50E-01	2.50E-03
Am-243	5.70E-01	8.60E-01	1.40E+00	4.70E-03
Ca-41	2.00E-04	0.00E+00	2.00E-04	6.60E-07
Ce-144	2.20E-03	7.90E-02	8.10E-02	2.60E-04
Cl-36	4.80E-04	6.70E-04	1.20E-03	3.80E-06
Cm-243	3.90E-01	3.70E-01	7.60E-01	2.50E-03
Cm-244	3.10E-01	7.90E-04	3.10E-01	1.00E-03
Cm-245	5.90E-01	3.50E-01	9.50E-01	3.10E-03
Cm-246	5.80E-01	8.60E-04	5.90E-01	1.90E-03
Cm-247	5.40E-01	6.10E-01	1.20E+00	3.80E-03
Co-57	1.30E-04	3.00E-01	3.00E-01	9.90E-04
Co-60	4.00E-03	3.20E+00	3.20E+00	1.10E-02
Cs-134	9.80E-03	2.00E+00	2.00E+00	6.60E-03
Cs-135	1.10E-03	0.00E+00	1.10E-03	3.70E-06
Cs-137	7.80E-03	8.50E-01	8.60E-01	2.80E-03
Eu-152	1.00E-03	1.80E+00	1.80E+00	5.80E-03
Eu-154	1.50E-03	1.90E+00	1.90E+00	6.10E-03
Fe-55	8.50E-05	0.00E+00	8.50E-05	2.80E-07
Mn-54	3.00E-04	8.30E-01	8.30E-01	2.70E-03
Na-22	1.60E-03	2.90E+00	2.90E+00	9.30E-03
Nb-94	1.10E-03	2.30E+00	2.30E+00	7.60E-03
Ni-59	3.30E-05	0.00E+00	3.30E-05	1.10E-07
Ni-63	9.10E-05	0.00E+00	9.10E-05	3.00E-07
Np-237	7.00E-01	5.70E-01	1.30E+00	4.20E-03
Pb-210	8.40E-01	1.20E-02	8.50E-01	2.80E-03
Pm-147	1.50E-04	4.20E-05	1.90E-04	6.10E-07
Pu-238	5.00E-01	9.30E-04	5.00E-01	1.70E-03
Pu-239	5.60E-01	4.00E-04	5.60E-01	1.80E-03
Pu-240	5.60E-01	8.90E-04	5.60E-01	1.80E-03
Pu-241	1.10E-02	1.90E-05	1.10E-02	3.50E-05
Pu-242	5.30E-01	7.50E-04	5.30E-01	1.70E-03
Ru-106	3.10E-03	2.50E-01	2.50E-01	8.20E-04
Sb-125	3.90E-04	6.10E-01	6.10E-01	2.00E-03
Se-79	1.40E-03	0.00E+00	1.40E-03	4.50E-06
Sm-151	6.10E-05	6.10E-06	6.70E-05	2.20E-07
Sr-90	2.20E-02	4.40E-03	2.70E-02	8.70E-05
Tc-99	2.30E-04	2.20E-04	4.50E-04	1.50E-06
Th-228	5.20E-02	1.90E+00	1.90E+00	6.20E-03
Th-229	5.60E-01	8.50E-01	1.40E+00	4.60E-03
Th-230	8.70E-02	2.10E-03	8.90E-02	2.90E-04
Th-232	4.30E-01	1.20E-03	4.30E-01	1.40E-03
U-232	2.10E-01	1.60E-03	2.10E-01	6.80E-04
U-233	4.60E-02	1.60E-03	4.70E-02	1.50E-04
U-234	4.50E-02	8.70E-04	4.60E-02	1.50E-04
U-235	4.20E-02	4.70E-01	5.10E-01	1.70E-03
U-238	4.00E-02	7.60E-02	1.20E-01	3.80E-04
Zn-65	1.40E-03	5.40E-01	5.40E-01	1.80E-03
Zr-93	2.60E-04	0.00E+00	2.60E-04	8.60E-07

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

[b] Inhalation doses do not apply for these scenarios.

TABLE D.29 Baseline Public Doses for a 100-t Batch — Highway Pavement Scenario[a]

Nuclide	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	3.40E-02	5.60E-04
Ag-110m	1.40E-01	2.30E-03
Am-241	1.10E-03	1.90E-05
Am-243	1.90E-02	3.10E-04
Ca-41	0.00E+00	0.00E+00
Ce-144	3.00E-03	5.00E-05
Cl-36	3.60E-05	5.90E-07
Cm-243	1.20E-02	1.90E-04
Cm-244	2.80E-06	4.60E-08
Cm-245	8.10E-03	1.30E-04
Cm-246	2.50E-06	4.20E-08
Cm-247	2.90E-02	4.80E-04
Co-57	7.90E-03	1.30E-04
Co-60	1.80E-01	2.90E-03
Cs-134	1.10E-01	1.80E-03
Cs-135	0.00E+00	0.00E+00
Cs-137	4.80E-02	7.90E-04
Eu-152	9.00E-02	1.50E-03
Eu-154	9.60E-02	1.60E-03
Fe-55	0.00E+00	0.00E+00
Mn-54	4.60E-02	7.60E-04
Na-22	1.60E-01	2.60E-03
Nb-94	1.30E-01	2.10E-03
Ni-59	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00
Np-237	2.00E-02	3.30E-04
Pb-210	6.20E-05	1.00E-06
Pm-147	1.00E-06	1.70E-08
Pu-238	3.50E-06	5.80E-08
Pu-239	7.20E-06	1.20E-07
Pu-240	3.50E-06	5.70E-08
Pu-241	4.20E-07	6.90E-09
Pu-242	3.00E-06	5.00E-08
Ru-106	1.40E-02	2.20E-04
Sb-125	3.20E-02	5.30E-04
Se-79	0.00E+00	0.00E+00
Sm-151	2.30E-08	3.90E-10
Sr-90	2.60E-04	4.30E-06
Tc-99	3.20E-06	5.30E-08
Th-228	1.00E-01	1.70E-03
Th-229	2.70E-02	4.50E-04
Th-230	2.80E-05	4.60E-07
Th-232	1.30E-05	2.10E-07
U-232	2.10E-05	3.40E-07
U-233	3.40E-05	5.60E-07
U-234	9.70E-06	1.60E-07
U-235	1.60E-02	2.60E-04
U-238	2.10E-03	3.40E-05
Zn-65	2.90E-02	4.80E-04
Zr-93	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

[b] Ingestion and inhalation doses do not apply for these scenarios.

TABLE D.30 Baseline Public Doses for a 100-t Batch — Public Building Scenario and Bridge Scenario[a]

	Public Building Scenario		Bridge Scenario	
Nuclide	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)	External[b] (μSv/yr)	Collective Dose (person-Sv/yr)
Ac-227	2.00E-02	3.30E-04	9.70E-01	1.60E-04
Ag-110m	1.00E-01	1.70E-03	1.30E+01	2.20E-03
Am-241	4.90E-04	8.00E-06	4.80E-06	7.80E-10
Am-243	9.60E-03	1.60E-04	1.90E-01	3.00E-05
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce-144	2.00E-03	3.30E-05	2.50E-01	4.00E-05
Cl-36	2.50E-05	4.00E-07	2.00E-03	3.30E-07
Cm-243	6.20E-03	1.00E-04	1.40E-01	2.30E-05
Cm-244	1.40E-06	2.30E-08	2.50E-09	4.10E-13
Cm-245	3.70E-03	6.20E-05	2.30E-02	3.70E-06
Cm-246	1.30E-06	2.20E-08	1.30E-12	2.10E-16
Cm-247	1.90E-02	3.10E-04	1.10E+00	1.80E-04
Co-57	3.70E-03	6.10E-05	2.70E-02	4.40E-06
Co-60	1.40E-01	2.30E-03	2.20E+01	3.50E-03
Cs-134	7.90E-02	1.30E-03	8.90E+00	1.50E-03
Cs-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	3.30E-02	5.50E-04	3.60E+00	5.90E-04
Eu-152	6.50E-02	1.10E-03	8.50E+00	1.40E-03
Eu-154	7.10E-02	1.20E-03	9.50E+00	1.60E-03
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	3.30E-02	5.50E-04	4.20E+00	6.90E-04
Na-22	1.10E-01	1.90E-03	1.40E+01	2.30E-03
Nb-94	9.30E-02	1.50E-03	1.10E+01	1.80E-03
Ni-59	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	1.10E-02	1.90E-04	4.50E-01	7.40E-05
Pb-210	2.70E-05	4.40E-07	4.60E-10	7.60E-14
Pm-147	4.90E-07	8.00E-09	2.60E-06	4.20E-10
Pu-238	1.70E-06	2.80E-08	2.20E-09	3.60E-13
Pu-239	3.30E-06	5.40E-08	1.30E-05	2.10E-09
Pu-240	1.70E-06	2.70E-08	1.40E-09	2.30E-13
Pu-241	2.00E-07	3.30E-09	2.30E-06	3.80E-10
Pu-242	1.40E-06	2.40E-08	3.20E-09	5.20E-13
Ru-106	9.40E-03	1.50E-04	9.30E-01	1.50E-04
Sb-125	2.20E-02	3.60E-04	1.80E+00	3.00E-04
Se-79	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm-151	1.10E-08	1.80E-10	0.00E+00	0.00E+00
Sr-90	2.10E-04	3.40E-06	3.70E-02	6.00E-06
Tc-99	1.40E-06	2.30E-08	1.60E-06	2.60E-10
Th-228	7.50E-02	1.20E-03	1.30E+01	2.10E-03
Th-229	1.60E-02	2.70E-04	1.00E+00	1.70E-04
Th-230	1.30E-05	2.20E-07	1.00E-04	1.70E-08
Th-232	5.80E-06	9.50E-08	2.00E-05	3.20E-09
U-232	9.90E-06	1.60E-07	6.50E-05	1.10E-08
U-233	1.60E-05	2.60E-07	6.40E-05	1.10E-08
U-234	4.50E-06	7.40E-08	1.70E-05	2.80E-09
U-235	8.30E-03	1.40E-04	1.20E-01	2.00E-05
U-238	1.30E-03	2.20E-05	1.40E-01	2.30E-05
Zn-65	2.20E-02	3.70E-04	3.20E+00	5.30E-04
Zr-93	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[a] Doses do not account for scrap dilution or radionuclide partitioning; collective doses based on 100 t.

[b] Ingestion and inhalation doses do not apply for these scenarios.

TABLE D.31 Public Doses for Stack Emission Scenario

Nuclide	Distance (m) of MEI[a]	Based on 100 t/yr of RSM: MEI Dose (μSv/yr)	Based on 100 t/yr of RSM: Collective Dose (person Sv/yr)	After Going through a HEPA Filter: MEI Dose (μSv/yr)	After Going through a HEPA Filter: Collective Dose (person Sv/yr)	Based on 50,000 t/yr of RSM: MEI Dose (μSv/yr)	Based on 50,000 t/yr of RSM: Collective Dose (person Sv/yr)
Ac-227	600E	1.4E-02	1.9E-03	7.1E-06	9.7E-07	3.5E-03	4.9E-04
Am-241	600E	1.2E-02	1.7E-03	6.1E-06	8.3E-07	3.0E-03	4.1E-04
Pu-239	600E	7.9E-03	1.0E-03	4.0E-06	5.2E-07	2.0E-03	2.6E-04
U-238	600E	2.7E-03	3.6E-04	1.3E-06	1.8E-07	6.7E-04	8.9E-05
Sr-90	100E	2.5E-03	6.2E-05	1.2E-06	3.1E-08	6.2E-04	1.6E-05
Tc-99	100E	4.4E-03	1.4E-04	2.2E-06	6.9E-08	1.1E-03	3.4E-05
Co-60	100E	1.1E-03	3.3E-05	5.7E-07	1.6E-08	2.8E-04	8.2E-06
Cs-137	100E	2.2E-01	2.0E-03	1.1E-04	1.0E-06	5.4E-02	5.0E-04
H-3	700E	1.5E-06	1.8E-07	7.5E-10	9.2E-11	3.8E-07	4.6E-08
C-14	700E	6.1E-05	4.4E-06	3.1E-08	2.2E-09	1.5E-05	1.1E-06
I-129	600E	2.4E-01	4.2E-03	1.2E-04	2.1E-06	5.9E-02	1.0E-03
Rn-222	700E	1.1E-05	2.0E-06	5.6E-09	1.0E-09	2.8E-06	5.0E-07
Rn-220	500E	2.7E-07	4.9E-11	1.3E-10	2.4E-14	6.6E-08	1.2E-11
Zn-65	100E	1.2E-02	3.4E-04	6.1E-06	1.7E-07	3.1E-03	8.5E-05
Th-228	700E	7.8E-03	1.1E-03	3.9E-06	5.5E-07	2.0E-03	2.8E-04
Th-232	700E	5.4E-03	7.7E-04	2.7E-06	3.9E-07	1.4E-03	1.9E-04
Ra-224	700E	7.6E-05	1.0E-05	3.8E-08	5.2E-09	1.9E-05	2.6E-06
Ra-226	600E	4.5E-04	3.3E-05	2.2E-07	1.7E-08	1.1E-04	8.3E-06

[a] MEI = maximally exposed individual.

TABLE D.32 Doses for Disposal Worker Scenario

	Dose (μSv/yr)			
	Volume-Contaminated RSM		Surface-Contaminated RSM	
Nuclide	Managed Landfill	Unrestricted Landfill	Managed Landfill	Unrestricted Landfill
Ac-227	5.30E-02	1.10E+02	6.60E-04	1.40E+00
Am-241	3.90E-06	1.70E+00	4.90E-08	2.10E-02
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	1.80E+00	8.90E+02	2.30E-02	1.10E+01
Cs-137	1.70E-01	2.00E+02	2.10E-03	2.50E+00
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I-129	9.60E-09	1.20E+00	1.20E-10	1.50E-02
Pu-239	9.10E-08	1.40E-02	1.10E-09	1.80E-03
Ra-226	2.30E+00	6.20E+02	2.80E-02	7.80E+00
Ra-228	7.30E-01	3.20E+02	9.10E-03	4.00E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc-99	2.20E-11	6.80E-05	2.80E-13	8.50E-07
Th-228	3.80E+00	5.40E+02	4.80E-02	6.80E+00
Th-230	3.10E-02	7.90E+00	3.90E-04	1.00E-01
Th-232	5.60E+00	8.20E+02	7.00E-02	1.00E+01
U-238	5.40E-03	4.90E+00	6.80E-05	6.10E-02
Zn-65	1.80E-01	1.50E+02	2.30E-03	1.90E+00

TABLE D.33 Doses for Disposal Resident Scenario

	Dose (μSv/yr)			
	Volume-Contaminated RSM		Surface-Contaminated RSM	
Nuclide	Managed Landfill	Unrestricted Landfill	Managed Landfill	Unrestricted Landfill
Ac-227	4.00E+01	4.50E+02	1.40E+00	8.30E+00
Am-241	1.20E+01	6.00E+01	4.40E-01	2.00E+00
C-14	1.40E+02	1.10E+03	0.00E+00	0.00E+00
Co-60	3.00E-01	1.70E+01	1.30E-02	2.50E-01
Cs-137	3.00E+00	2.00E+02	2.50E-01	1.80E+00
H-3	1.50E+00	1.30E+00	0.00E+00	0.00E+00
I-129	3.80E+03	3.00E+03	0.00E+00	6.30E-04
Pu-239	1.30E+01	5.60E+01	5.00E-01	2.30E+00
Ra-226	1.30E+04	1.20E+03	4.50E+02	3.80E+01
Ra-228	3.00E+00	3.00E+01	1.30E-01	8.30E-01
Sr-90	7.00E+01	1.50E+02	2.60E+00	5.80E+00
Tc-99	1.30E+01	1.30E+02	0.00E+00	0.00E+00
Th-228	0.00E+00	1.00E-02	0.00E+00	1.90E-04
Th-230	4.90E+02	3.00E+01	6.10E+00	1.30E+00
Th-232	1.70E+02	7.50E+02	6.30E+00	3.00E+01
U-238	1.80E+00	1.10E+01	6.90E-02	5.00E-01
Zn-65	0.00E+00	0.00E+00	0.00E+00	0.00E+00

APPENDIX E:

ENVIRONMENTAL RISK CONTEXT AND PROFILES OF TOXIC SUBSTANCES AND ASSOCIATED HEALTH EFFECTS

APPENDIX E:

ENVIRONMENTAL RISK CONTEXT AND PROFILES OF TOXIC SUBSTANCES AND ASSOCIATED HEALTH EFFECTS

Section E.1 presents information regarding the environmental risk context within which decisions will be made regarding radioactive scrap metal (RSM) management. This material is intended to provide perspective on the risk levels associated with the RSM alternatives. Section E.2 presents risk profiles of chemicals that would be released from processes associated with the RSM alternatives.

E.1 ENVIRONMENTAL RISK CONTEXT

Information regarding public and worker risks associated with the possible recycling of contaminated metals should be considered in the context of risks from common hazards and activities. Such a comparison of relative risks provides a basis for determining which risk-reduction efforts should be given priority and which costs of reducing, or avoiding, risks are worth incurring. This section presents an overview of risks to workers and to the public from common substances and activities. It also indicates the range of costs incurred in the U.S.A. per fatality averted as a result of recent regulations to reduce risk.

E.1.1 Radiation-Related Risks

Health risks associated with radiation exposures of the general population occur from radiation sources ranging from cosmic radiation and terrestrial materials, to diagnostic and therapeutic medical treatment, to industrial and medical occupational activities. Nonmedical sources of exposure to major segments of the population are identified in this section.

E.1.1.1 Industrial Activities

Occupational exposure to radiation occurs among several groups other than nuclear workers. The occupational categories of exposed workers, the sources of the exposure, and the average dose levels are shown in Table E.1. The groups receiving the largest annual exposures are industrial radiographers and well-loggers working in the oil industry. Next are aircraft crews and workers in rock phosphate production. For comparison, the average dose to nuclear power workers in Great Britain is about 1 mSv/yr, with just a few workers receiving doses greater than 5 mSv/yr (Health and Safety Executive 1992).

TABLE E.1 Occupational Exposure of Nonnuclear Workers

Occupational Category	Radiation Source	Number Exposed in U.S.A	Mean Annual Effective Dose Equivalent (mSv)	Risk of Fatal Cancer from Annual Exposure[a]
Medical[b]	Diagnostic X-ray machines	584,000	0.7-1.5	4×10^{-5} - 8×10^{-5}
U.S. Public Health Service[b]	Various sources	5,000	0.07-0.47	4×10^{-6}- 2×10^{-5}
Industrial radiographers[b]	Co-60 or Ir-192	8,500	2.8-4.3	1×10^{-4} - 2×10^{-4}
Well loggers[b]	Co-60 or Ir-192	8,700	3.5-4.2	2×10^{-4}
Phosphate fertilizer production plant and storehouse workers[c]	Uranium-natural, Ra-226, thorium-natural, K-40	NA[d]	0.11-0.45	6×10^{-6} - 2×10^{-5}
Rock phosphate production and transport workers[c]	Uranium-natural, Ra-226, thorium-natural, K-40	NA	0.3-3.0	2×10^{-5} - 2×10^{-4}
Aircraft crew[b]	Cosmic radiation	97,000	1.7	9×10^{-5}

[a] From NCRP (1989); low end of range represents all professionals in field, while high end represents those operating equipment.

[b] From Wehner (1978).

[c] NA = data not available.

[d] The risk of fatal cancer was calculated with a risk factor of 5.0×10^{-2}/Sv for the general public (ICRP 1990).

E.1.1.2 Consumer Products

Radiation is associated with consumer products in both intentionally added and naturally occurring forms and as an unintended by-product of product operation. Some of the major types of products with which the public in industrialized countries is likely to come into contact are listed in Table E.2. Among these products, the highest doses are associated with use of tobacco products, in which the radioactivity occurs naturally. The next largest doses, which are substantially smaller, are by-products of color TV and video display terminal operation.

Watches with luminescent displays are probably the most common personal products to which radioactivity is intentionally added. Historically, radium was painted on watch hands or dials to render them luminous. This practice has been replaced by the use of tritium in liquid crystal display devices. The watch casing shields the wearer from any exposure, and the only way that potential exposure could occur is through ingestion or inhalation of the liquid tritium if the casing breaks.

Uranium may be added to the material used for ceramic dentures and dental prostheses in order to impart a natural-looking color. The annual effective equivalent dose to the exposed population is relatively low, on the order of 0.7 μSv. This dose is in addition to the 1.4-1.9 mSv dose equivalent from K-40 in the ceramic material. While as many as 45,000,000 people in the U.S.A are estimated to be using this material (National Council on Radiation Protection and Measurements [NCRP] 1987a), it is unlikely that many are aware of the uranium content. Recently, this use has been largely phased out by the introduction of acrylic products.

E.1.1.3 Environmental Radiation Exposure

Small quantities of radioactive elements occur naturally in rock, soil, water, and air and are incorporated into living organisms. The concentrations of these radioactive materials range from trace levels to levels sufficient to cause measurable cell damage in humans. Even the materials with higher levels of activity are generally used without regard for their radioactivity and in a few cases are considered by local populations to have therapeutic value.

Table E.3 includes both commonly used substances that give rise to radiation exposures and some that are relatively unusual. Mineral-based building materials, domestic water supplies, and agricultural fertilizers have average annual dose equivalents ranging up to 50-70 μSv for the exposed population. The doses from these substances are considerably larger than those from any of the consumer products, in which the radiation is man-made.

The radioactivity level in seawater is about the same as the high-end level for drinking water, but the activity is due to the presence of K-40 rather than dissolved radon. In buildings made of granite, K-40 raises dose levels due to external exposure for building occupants. These levels are likely to be higher than those listed in Table E.3 for concrete or

TABLE E.2 Population Exposure from Consumer Products in the U.S.A.

Product	Radiation Source	U.S.A. Population Exposed	Mean Annual Effective Dose Equivalent to an Exposed Individual (μSV)	Risk of Fatal Cancer from Annual Exposure[a]
Color TV screens	By-product X-rays	230,000,000	<10	$<5 \times 10^{-7}$
Video display terminals	By-product X-rays	50,000,000	<10	$<5 \times 10^{-7}$
Airport luggage inspection systems	Intentional X-rays	30,000,000	0.021	1×10^{-9}
Luminescent watches and clocks	Tritium	10,750,000	1	5×10^{-8}
Electron tubes, appliance indicator lights, electric blanket thermostats	Various isotopes with activities <37 kBq per unit	230,000,000	0.04	2×10^{-9}
Smoke detectors	Am-241	—[b]	0.08	4×10^{-9}
Tobacco products	Po-210	50,000,000	13,000	7×10^{-4}
Natural gas cooking ranges	Radon	125,000,000	4	2×10^{-7}
Ophthalmic glass	Thorium and uranium	50,000,000	<4	$<2 \times 10^{-7}$
Gas lantern mantles	Thorium	50,000,000	2	1×10^{-7}
Fluorescent lamp starters	Thorium	50,000,000	0.0002	1×10^{-11}

[a] The risk of fatal cancer was calculated with a risk factor of 5.0×10^{-2}/Sv for the general public (ICRP 1990).

[b] About 100 million units in use.

Source: NCRP (1987a).

TABLE E.3 Naturally Occurring Radioactive Concentrations in the Environment

Substance	Radiation Source	Concentration	Mean Annual Effective Dose Equivalent to an Exposed Individual (μSv)	Risk of Fatal Cancer from Annual Exposure[a]
Domestic water supplies (U.S.A.)[b]	Radon	1,400-8,100 Bq/L[c]	10-60	5×10^{-7} - 3×10^{-6}
Concrete or brick home[b]	Uranium, thorium, potassium	—[d]	70	4×10^{-6}
Agriculture fertilizer[b]	Uranium, thorium, potassium	—	5-50	3×10^{-7} - 3×10^{-6}
Seawater[e]	Potassium	8,100 Bq/L	—	—
Granite[f]	Potassium	1,100 Bq/g	—	—
Shale[e]	Potassium	590 Bq/g	—	—
Pre-World War II steel[e]	Uranium	0.01-0.2 ppm	—	—
Human skeleton[e]	Ra-226	0.62 Bq/g Ca in bone	—	—
Brazil nuts[e]	Radium	380 Bq/g	—	—
Cereals[e]	Radium	16 Bq/g	—	—
Mineral springs[e]				
- Saratoga, N.Y.	Radium	7,600-14,000 Bq/L	—	—
- Bad Gastein, Austria	Radium	2,700 Bq/L	—	—

[a] The risk of fatal cancer was determined with a risk factor of 5.0×10^{-2}/Sv for the general public (ICRP 1990).

[b] NCRP (1987a).

[c] Population-weighted average.

[d] — denotes data not available.

[e] Eisenbud (1987).

[f] Conference of Radiation Control Program Directors, Inc. (1978).

brick houses. Samples of steel produced before World War II, and the release of man-made radioactivity, showed traces (0.01-0.2 ppm) of natural uranium content. Traces of radium, which is chemically similar to calcium, occur in many foods. Cereals are at the high end of the range of concentrations found in common types of foods.

Finally, Table E.3 presents radium concentrations in mineral spring waters that are renowned for their putative health benefits. People both drink the waters and immerse themselves in them, seeking their curative effects. In addition to the springs listed, similar sites are located in Greece (springs) and in Brazil (sands) with relatively long histories of therapeutic use.

People experience much more significant (in terms of magnitude) exposures from environmental radiation than from consumer products (other than tobacco). As shown in Table E.4, the largest exposure source is inhalation of radon and its decay products. This

TABLE E.4 Sources of Population Exposure to Environmental Radiation

Source	Annual Dose Equivalent (μSv)	Risk of Fatal Cancer from Annual Exposure[a]
Cosmic radiation, including air travel	270	1×10^{-5}
Terrestrial gamma radiation	280[b]	1×10^{-5}
Inhaled radon and its daughters	2,000[c]	1×10^{-4}
Radionuclides incorporated in body tissues	390	2×10^{-5}
Coal combustion	0.3-3.0	2×10^{-8} - 2×10^{-7}
Fallout from nuclear weapons testing	<1	$<5 \times 10^{-8}$
Nuclear fuel cycle	0.5	3×10^{-8}

[a] The risk of fatal cancer was calculated with a risk factor of 5×10^{-2}/Sv for the general public (ICRP 1990).

[b] In the U.S.A., the range is from 160 μSv on the Atlantic and Gulf coasts to 630 μSv on the eastern slopes of the Rocky Mountains.

[c] Average estimated at 1 mSv in the United Kingdom (Health and Safety Executive 1992).

Source: NCRP (1987b).

hazard varies geographically with area geology and also varies with indoor air circulation. Terrestrial gamma radiation levels also differ greatly around the world, with about 200-600 mSv/yr being considered the normal range (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR] 1982). In the U.S.A., the range is approximately from 160 to 630 μSv. Additional doses are received from cosmic radiation and from isotopes that have been incorporated into body tissues, especially K-40. Man-made sources contribute much smaller increments to the total annual dose equivalent. Of these activities, coal combustion is one of the main radioactive emission sources.

E.1.2 Nonnuclear Risks to Life and Health

Risks from common hazards and activities that are nonnuclear in nature also provide an indication of the baseline level of societal risk. A range of these hazards is summarized in the next section, followed by a brief summary of some risks that have been considered sufficiently substantial to require regulation, and the expenditure levels per fatality averted by the regulation.

E.1.2.1 Risk Associated with Common Hazards

To the degree that the public is informed about risks, the activities and investments chosen by a society provide some indication of the risk levels that are considered acceptable, given the benefits of participating in the activity. Fatality risks from participation of broad segments of the U.S.A. population in normal, daily activities are shown in Table E.5. The figures indicate the average risk to an exposed individual per year and the uncertainty level associated with that estimate. These activities were selected to present a range of voluntary and involuntary risks involving consumption decisions and common household and business activities. The risk levels range from a high of 3.6×10^{-3} fatalities for persons smoking a pack of cigarettes per day to a low of 6×10^{-7} fatalities from drinking water that contains chloroform at the upper limit of the U.S. Environmental Protection Agency (USEPA) standard.

E.1.2.2 Regulated Risk Reduction and Associated Costs

During the past 20 years, risk regulation has been a major emphasis in the U.S.A, especially at the federal level. Table E.6 provides information on a few of the standards, specifically related to hazardous materials or consumer products, developed during this period. Generally, annual residual risk levels of 10^{-4} to 10^{-6} are considered "acceptable"; however, three of the listed regulations addressed baseline risk levels that were well within the "acceptable" level. Of these three, one involved protection of children, at a relatively low cost per fatality avoided. The other two were developed during the last five years and involve very high costs for the decrease in fatality risks. This development is a clear break from the previous trend and indicates a very strong demand for reduction of even minimal risk levels.

TABLE E.5 Fatality Risks Associated with Common Activities in the U.S.A.

Activity	Mean Annual Risk of Fatality	Uncertainty
Cigarette smoking (one pack/day)	3.6×10^{-3}	Factor of 3
Motor vehicle accident (total)	2.4×10^{-4}	10%
Alcohol consumption (light drinker)	2×10^{-5}	Factor of 10
Home accidents	4.2×10^{-5}	5%
Frequent air travel	5×10^{-5}	50%
Eating peanut butter (4 tablespoons/day)	8×10^{-6}	10%
Drinking water with EPA limit of chloroform	6×10^{-7}	Factor of 10

Source: Wilson and Crouch (1987).

E.2 PROFILES OF TOXIC SUBSTANCES AND ASSOCIATED HEALTH EFFECTS

Many different toxic substances may be released as a result of the process alternatives for RSM management. This section indicates some of the health risks associated with substances identified as of potential concern for the RSM alternatives.

E.2.1 Benzene

Benzene is toxic by ingestion, inhalation, and skin absorption. Single oral or inhalation exposures to benzene at 20,000 ppm have proven to be fatal in humans. Industrial air concentrations of benzene have been reported to give rise to giddiness, drowsiness, dizziness, headache, nausea, convulsions, unconsciousness, and paralysis (U.S. Department of Health and Human Services [DHHS] 1989d; National Research Council 1977). Long-term exposures to benzene may affect normal blood production, possibly resulting in severe anemia and internal bleeding. Benzene has been found harmful to the immune system, increasing the chance for infections and perhaps lowering the body's defense against tumors. Exposure to benzene has also been linked with genetic changes (DHHS 1989d; Szpunar 1993).

TABLE E.6 Baseline Mortality Risk Levels and Costs Associated with Selected U.S.A Regulations

Regulation	Initial Lifetime Morality Risk for Exposed Population	Estimated Cost per Premature Death Avoided ($10^6 1990)
Ban on flammable children's sleepwear	2.9×10^{-5}	0.6
Standards for radionuclides in uranium mines	6.3×10^{-3}	3.4
Arsenic emission standards for glass plants	2.7×10^{-3}	13.5
Treatment of petroleum refining sludge as hazardous waste	2.1×10^{-4}	27.6
Cover/move inactive uranium mill tailings sites	3.0×10^{-2}	31.7
Hazardous waste land disposal ban	2.0×10^{-6}	4,190
Treatment of wood-preserving chemical as hazardous waste	$<1.0 \times 10^{-6}$	5,700,000

Source: U.S. Government Printing Office (1991, p. 370).

From overwhelming human evidence and supporting animal studies, benzene is known to be a human carcinogen. Leukemia (cancer of the tissues that form the white blood cells) and subsequent death from cancer have occurred in some workers exposed to benzene for periods of less than 5 years. The California Department of Health Services, in addition to the U.S. Environmental Protection Agency, has assumed that there is no threshold for benzene-induced carcinogenicity (DHHS 1989d; USEPA 1993).

E.2.2 Toluene

Toluene is toxic by ingestion, inhalation, and skin absorption. Information on acute human exposure to toluene suggests a narcotic effect at approximately 200 ppm. Irritation to eyes and the upper respiratory tract may occur at 100 ppm. Industrial exposure for several years at a mean atmospheric toluene concentration of 125 ppm has not produced any detectable change in blood characteristics or in liver function, although workers exposed to toluene at 100-1,100 ppm from two weeks to five years have demonstrated evidence of mild red-cell decrease, enlarged liver, and increased mean corpuscular hemoglobin concentration. However, a literature search failed to confirm any clinical or laboratory evidence of altered

liver function in workers exposed to 80-300 ppm over many years (National Research Council 1977; DHHS 1989a; Szpunar 1992).

Short-term exposure affects the nervous system, producing lightheadedness and euphoria at first, followed by fatigue, confusion, general weakness, dizziness, sleepiness, drunken-type actions, memory loss, nausea, loss of appetite, unconsciousness, and (in some cases) death because the person cannot breathe. These symptoms disappear when exposure is stopped. Long-term exposure has been linked with permanent damage to the brain, affecting speech, vision, and hearing and resulting in loss of muscle control, memory, and balance (DHHS 1989a; Szpunar 1992).

E.2.3 Polycyclic Organic Matter

Polycyclic organic matter (POM), a chemical class including numerous organic compounds, primarily large, fused-ring, polynuclear aromatic hydrocarbons (PAHs), is listed as a single category in the 1990 Clean Air Act Amendments (CAAA). (The 1990 CAAA listing contains 170 individual organic compounds, plus the generic class of POM.) Although benzidine, dibenzofuran, and naphthalene are singled out as individual Clean Air Act hazardous air pollutants, they are typically considered in the class of POM, which may include more than 100 compounds. The POM compounds tend to be toxic by inhalation or skin absorption, and over long periods of exposure some have been determined to be carcinogenic. Specifically, benzidine (as a carcinogen) and dibenzofuran (as a noncarcinogen) are cited by the U.S. Environmental Protection Agency (Hassett-Sipple 1991) as high-risk pollutants (Szpunar 1993).

Some of the most powerful carcinogens are derivatives of 1,2-benzanthracene (four fused, aromatic rings). These may include 5,10-dimethyl-1,2-benzanthracene, 1,2,5,6-dibenzanthracene (five fused, aromatic rings), methylcholanthrene (five rings — four fused, aromatic), and 3,4-benzpyrene (five fused, aromatic rings) (Morrison and Boyd 1966; Szpunar 1993).

Although the health effects of the individual organic compounds comprising POM are not exactly alike, some characteristics are considered representative of the class. These compounds may enter the body quickly and easily by inhalation, ingestion, and skin absorption. They tend to migrate to the fatty tissues of the body, and tend to be stored primarily in the kidneys, liver, and fat, with smaller amounts in the spleen, adrenal glands, and ovaries. Most exit through the excretory system within a few days. Human exposure by breathing or skin contact for long periods may result in cancer. Animal studies indicate harmful reproductive and immune system effects, birth defects, and decreased body weight. The following specific organic compounds are examples (DHHS 1990a; Szpunar 1993).

E.2.3.1 Benzidine

Benzidine is toxic by ingestion, inhalation, and skin absorption and is carcinogenic. Acute (short-term) exposure to large amounts can cause skin rashes, irritation, and damage to certain body tissues and organs, such as the bladder. Long-term exposure can result in bladder damage (lesions), which may progress to invasive cancer if not found and treated in the early stages. The time required for the development of cancer decreases as the level of exposure increases (DHHS 1989b; Szpunar 1993).

E.2.3.2 Benzo(a)pyrene

Benzo(a)pyrene is toxic by inhalation and is an active carcinogen (Hawley 1977). Preliminary estimates of the potential health impacts from the emissions of POM and PAHs from coal combustion and coal conversion processes were made using benzo(a)pyrene or benzene-soluble organic materials. In fact, the health impacts from PAHs from coal, coal combustion, and coal conversion have been estimated by comparing the actual benzo(a)pyrene exposures and associated health risks with those of coke oven workers (DOE 1980).

E.2.3.3 Dibenzofuran

Dibenzofuran is probably toxic; however, no toxicological profile by the U.S. Department of Health and Human Services was available for review of dibenzofuran at this time (Szpunar 1993).

E.2.3.4 Naphthalene

Naphthalene is toxic primarily by inhalation but also by ingestion and skin absorption. Hemolytic anemia (a condition involving the breakdown of the red blood cells) is the primary health concern for humans exposed for either short or long periods. Other common effects include nausea, vomiting, diarrhea, kidney damage, jaundice, and liver damage. Cataracts may also be caused by inhalation exposure. Neither cancer nor birth defects have been demonstrated (DHHS 1990b; Szpunar 1993).

E.2.3.5 Dioxin

Dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) is toxic by ingestion, inhalation, and skin absorption. In humans, it causes chloracne, a severe skin lesion that usually occurs on the head and upper body. Chloracne is more disfiguring than common acne and often lasts for years after the initial exposure. Chloracne may cause liver damage, loss of appetite, weight loss, and digestive disorders in humans. Animal studies have indicated toxicity to the immune system, spontaneous abortions, malformations in offspring, weight loss resulting in death, and carcinogenicity (DHHS 1987; Szpunar 1993).

E.2.4 Compounds of the Trace Elements

E.2.4.1 Arsenic

Arsenic compounds are toxic by ingestion (primarily), inhalation, and skin absorption (to a much lesser extent); they may also be carcinogenic. Arsenic has been recognized as a human poison since ancient times, and large doses can produce death. Lower levels of exposure may produce injury in a number of different body tissues or systems (Szpunar 1992).

A common effect in humans by ingestion is irritation of the digestive tract, leading to pain, nausea, vomiting, and diarrhea. Other effects include decreased production of red and white blood cells, abnormal heart function, blood vessel damage, liver and/or kidney injury, impaired nerve function causing a "pins and needles" feeling in the hands and feet, and skin abnormalities. Arsenic ingestion has been reported to increase the risk of cancer in the liver, bladder, kidneys, and lungs. Inhalation exposure may produce the same types of systemic health effects produced by ingestion, but in a much milder form; of greater concern is lung cancer. Dermal contact may result in mild to severe irritation of the skin, eyes, or throat. On the other hand, despite all the adverse health effects associated with arsenic exposure, there is some evidence that low levels of exposure may be beneficial to good health. Although no cases of arsenic deficiency in humans have been found, animal deficiencies have been documented (DHHS 1989e; Szpunar 1992).

E.2.4.2 Beryllium

Beryllium can be toxic, depending on the amount and duration of exposure. Not all of the effects that beryllium and its compounds have on human health are well understood, and not all forms are equally toxic. Short-term human exposure to soluble beryllium compounds can cause the development of inflammation and swelling of the lungs; removal from exposure results in a reversal of symptoms. Long-term exposure has been reported to cause chronic beryllium disease in sensitive individuals, characterized by shortness of breath, scarring of the lungs, and berylliosis (noncancerous growths in the lungs). Both acute and chronic beryllium disease can be fatal, depending on the severity of the exposure. Dermal contact may develop into a skin allergy for sensitized individuals; noncancerous growths may form on the skin if beryllium enters cuts. Inhalation of beryllium and its compounds is presumed by the U.S. Environmental Protection Agency to have some cancer-causing potential in the human lung (DHHS 1988a; Szpunar 1992).

E.2.4.3 Cadmium

Cadmium is not known to have any beneficial effects, and it can cause a number of adverse health effects. Cadmium is toxic to virtually every system in animals, whether ingested, injected, or inhaled. Ingestion of high doses causes severe irritation to the stomach,

leading to vomiting and diarrhea; inhalation of high doses leads to severe irritation of the lungs. Of greater concern is long-term, low-level exposure, which causes kidney and lung damage and lung cancer. Exposure injures the liver, the testes, the immune system, the nervous system, and the blood. A low but prolonged intake of cadmium is suspected to lead to hypertension and reduced longevity in laboratory animals (DHHS 1989f; Szpunar 1993).

Cadmium is highly toxic, especially by inhalation of dust or fume. It may be fatal. Cadmium plating of food and beverage containers has resulted in a number of outbreaks of gastroenteritis (food poisoning). With respect to dust and soluble compounds, the cadmium tolerance is 0.2 mg/m^3 of air; for oxide fume its tolerance is 0.1 mg/m^3 of air. Soluble compounds of cadmium are highly toxic; however, ingestion usually induces a strong emetic action (vomiting), which minimizes the risk of fatal or severe poisoning (Hawley 1977; Szpunar 1992).

Schroeder (1967) showed a positive correlation between the cadmium levels in air in U.S.A. cities and the incidence of cardiovascular diseases in those cities. The disease of *itai-itai* in Japan has now been well-documented as being caused by the ingestion of cadmium, zinc, and lead from mining operations (Szpunar et al. 1980; Szpunar 1992).

E.2.4.4 Chromium

Although considered an essential nutrient in the trivalent state required for normal metabolism of carbohydrate, glucose, cholesterol, and fat in humans, chromium compounds in the hexavalent state are highly toxic by inhalation, ingestion, and skin absorption and probably carcinogenic by inhalation (Szpunar 1992).

Although exposure to metallic chromium is not well-characterized, elemental chromium and its trivalent compounds are relatively nontoxic. Cr^{+3} occurs naturally in soil, volcanic dust, and gases; it has not been found to be toxic, even when associated with wastewaters and industrial discharges. Nevertheless, although short-term exposure to Cr^{+3} does not generally appear to result in adverse health effects, very large doses of Cr^{+3} may prove harmful (DHHS 1989c; Szpunar 1992).

Signs of Cr^{+3} deficiency in humans include weight loss and impairment of the body's ability to remove glucose from the blood. The minimum human daily requirement of Cr^{+3} for optimal health is not known, but a daily ingestion of 50-200 µg per day has been estimated to be safe and adequate. Brewer's yeast and fresh foods are good sources of Cr^{+3} (DHHS 1989c; Szpunar 1992).

Short-term exposure to Cr^{+6}, on the other hand, can result in adverse effects at the site of contact. The hexavalent compounds have an irritative and corrosive effect on tissue, resulting in ulcers and dermatitis on prolonged contact (e.g., irritation of the nasal mucosa, perforation of the nasal septum, and irritation of the gastrointestinal tract). It may also cause adverse effects in the kidney and liver (Hawley 1977; DHHS 1989c; Szpunar 1992).

Long-term exposure of workers to airborne levels of Cr^{+6} has been associated with lung cancer, occurring long after exposure to Cr^{+6} has ended. Compounds of Cr^{+6} are regarded as probable cancer-causing substances in humans exposed by inhalation. Inhalation exposure to Cr^{+6} may also result in adverse effects on the respiratory system and may affect the immune system. Tolerance for chromium dust and fume is 1 mg/m^3 of air (Hawley 1977; DHHS 1989c; Szpunar 1992).

E.2.4.5 Lead

Probably no other element besides mercury has been subjected to greater research efforts than lead. The long-standing problem of lead toxicity in humans has been well documented. Toxic primarily by inhalation and ingestion, especially with respect to its organic compounds (lead alkyls), lead compounds may also be carcinogenic. Regardless of how lead enters the body, most of it accumulates there and remains stored in the teeth and bone (Szpunar 1992).

People with more than 0.5 ppm lead in their blood show visible signs of lead poisoning — constipation, headaches, anemia, paralysis, blindness, insanity, and, finally, at higher levels, death. Also, lead can cause sterility, miscarriage, still births, and infant mortality and mental retardation (Szpunar 1992).

There is no well-established role for lead as an essential trace element in nutrition. However, lead is a well-known cumulative poison in humans. Generally, lead enters the body by inhalation or ingestion, but much less lead enters through the skin than through the lungs or gastrointestinal tract. The effects of lead are the same no matter how it enters the body. Because some lead is stored in the body each time a person is exposed, the levels of lead in bone and teeth increase as one gets older. Unstored lead is removed through the excretory system (DHHS 1990c; Szpunar 1992).

Exposure is especially dangerous for the unborn because their bodies can be harmed while they are being formed, resulting in premature birth, low birth weight, or spontaneous abortion. Young children are at risk because they may ingest significant amounts of lead when they put toys or other objects soiled with lead-containing dirt in their mouths. For infants or young children, exposure has been shown to decrease intelligence scores, slow growth, and cause hearing problems. These effects appear to last as children get older and can interfere with successful performance in school. Moreover, these health effects can occur at exposure levels once thought to be safe (Szpunar et al. 1980; Szpunar 1992).

Exposure to high levels of lead can cause brain and kidney damage in adults and children, may increase blood pressure in middle-aged men, and may affect the male reproductive system, especially sperm. Although lead has not been shown definitely to cause cancer in humans, laboratory animals have developed tumors, indicating the same possibility in humans (DHHS 1990c). Organic compounds, especially lead alkyls, are even more poisonous than the inorganic compounds of lead. Therefore, because of the wide array of

organic compounds potentially emitted from coal-fired combustion, lead potentially poses a significant threat to man (Szpunar 1992).

E.2.4.6 Nickel

Exposure to nickel and its compounds results from breathing air, ingesting drinking water and food that contain nickel and its compounds, and skin contact with a wide range of consumer products. Very small amounts of nickel have been shown to be essential for normal growth and reproduction in some species of animals; thus, small amounts of nickel are also thought to be essential to nutrition in humans. Nickel is a cofactor of the enzyme urease and can substitute for calcium in some processes (DHHS 1988b; Szpunar et al. 1980; Szpunar 1992).

The most common adverse effects of nickel exposure noted in the general population are skin allergies. Surveys indicate that 2.5-5.0% of the population may be sensitive to nickel. Individuals may be sensitized by frequent or prolonged contact with nickel-containing or nickel-plated consumer products such as jewelry. However, in persons not sensitive to nickel, normal long-term oral, inhalation, and skin exposures to low levels of nickel have not been associated with adverse health effects. Accidental or suicidal ingestion of very high amounts of some nickel compounds (but not nickel metal) may result in death (Szpunar 1992).

Inhalation in the work place has produced asthma in nickel platers exposed to nickel sulfate ($NiSO_4$) and in welders exposed to nickel oxide (NiO_x). From the inhalation of nickel refinery dust, which contains nickel subsulfide, increased deaths from lung and nasal cavity cancers and possible voice-box cancer have been reported. However, there are no nickel refineries in the U.S.A. and, hence, no nickel refinery dust and no nickel subsulfide (DHHS 1988b; Szpunar 1992).

The carcinogenesis of nickel is inversely related to the solubility of its compounds, and the least soluble in aqueous media appear to be the most carcinogenic. Nickel carbonyl has been implicated as a possible carcinogen in metal workers and tobacco smokers (Szpunar et al. 1980; Szpunar 1992).

E.2.4.7 Selenium

About 50-150 µg per day of selenium is required in the human diet. Selenium and most of its compounds are not considered to be carcinogenic; in fact, several studies suggest that normal amounts of dietary selenium may protect against cancer. However, selenium sulfide has been shown to be carcinogenic in animals via ingestion. Selenium compounds have not been shown to cause reproductive effects in humans or other mammals (Agency for Toxic Substances and Disease Registry 1989).

High dietary concentrations of selenium can cause brittleness and loss of nails and hair, dermatitis, swelling, numbness or tingling in the extremities, and pain in the limbs. In

severe cases of selenium poisoning, paralysis may develop. Estimates of selenium absorption from the digestive tract range from 44 to 100%, and insoluble elemental selenium is probably poorly absorbed. The no observed adverse effect level for selenium was estimated from a correlation between blood selenium levels that were shown to reflect clinical signs of intoxication and the estimated intake levels (Agency for Toxic Substances and Disease Registry 1989).

Respiratory tract irritation can result from short-term inhalation of high levels of selenium dusts or selenium compounds in industrial settings; nausea, elevated pulse rate, and irritation of the skin and eyes have also been reported. Absorption is dependent on the chemical form of selenium, but limited data indicate that both elemental selenium and selenious acid are absorbed via inhalation. A standard reference concentration is not currently available to assess inhalation exposures. Dermal contact with selenium dust and selenium dioxide can cause dermatitis, but data are not available to quantify dermal absorption.

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APPENDIX F:

QUESTIONNAIRE ON RECYCLING AND LIST OF RESPONDENTS

APPENDIX F:

QUESTIONNAIRE ON RECYCLING AND LIST OF RESPONDENTS

F.1 QUESTIONNAIRE ON RECYCLING

Argonne National Laboratory is conducting an evaluation of recycling currently contaminated radioactive scrap metal. Part of this study assesses the opinions and position of the industry, environmental groups, and other concerned parties. To assist us in this effort, please provide answers to the following questions, with supporting documentation as requested:

1. Name/Affiliation/Address/Phone Number:

_____

_____

_____

_____

2. Has your organization taken a position in the past on BRC, (Below Regulatory Concern) regulations proposed by NRC? What was that position, and could you provide your written rationale, e.g. testimony, position paper etc.?

_____

_____

_____

_____

3. Does your organization have a position on the recycling of radioactive scrap metal? If yes, could you provide any rationale that has been developed?

4. What are your major concerns regarding the recycling of radioactive scrap metal?

5. If recycling was proposed for only radioactive scrap metal with trace amounts of contamination would your group be more likely, or less likely to (support) or (oppose) such an approach? Why?

6. Considering that the alternative to recycling some radioactive scrap metal is disposal, and that disposal creates additional problems of its own, how do you evaluate the trade-offs of recycling v. disposal?

7. Have you or your group completed, or have available, any evaluations, analyses, or other background materials on your position? Please provide if possible.

8. Are there any other groups or individuals you would suggest we interview for this study? Please provide names and phone numbers:

9. Do you have any other comments or suggestions regarding the recycling of radioactive scrap metal?

Thank you for your time and interest. Please use additional sheets as necessary. Call me with any questions at 202/488-2448.

Please return this form by January 8, 1993, to:

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