DRAFT

RECYCLE/REUSE
LITERATURE SEARCH REPORT

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Preface

This report summarizes a literature search conducted as the first of five tasks under an NRC contract entitled *Guidance and Models for Reuse/Recycle Material*. This Task 1 report discusses background information on reuse and recycle of contaminated equipment and material from NRC licensed facilities. The information was originally intended to provide the basis for subsequent tasks, primarily Task 2, where dose assessments are estimated for potential exposure scenarios related to reuse and recycle. Although Task 1 was scheduled to be seven months in duration, the work was initiated in late 1992 and was completed in early 1994.

Information from the Task 1 literature search provided an adequate basis to initiate Task 2. Task 2 began in late 1993 and was to be completed within 2 years after completion of Task 1 (~ 1996). However, as Task 2 progressed, the scope of the project grew and background information not contained in the Task 1 draft report was required. Also, unavoidable project delays and other NRC commitments (e.g., the recent rulemaking addressing radiological criteria for decommissioning) resulted in lengthening the period for completion of Task 2. During this extended time, significant additions to the literature that were relevant to Task 2 were published, including a draft report published by the EPA and an IAEA report addressing recycle of material. New information was incorporated into Task 2, but the Task 1 draft report was not updated.

This Task 1 report is being published as a historical baseline for completion of Task 2. Information and terminology used in this report are not current and are not always consistent with the separately published Task 2 report (to be published as NUREG-1640). For example, this report uses the term "recyclable scrap metal (RSM)", which is not used in NUREG-1640 because of confusion over its meaning. Also, this report uses different units and unit abbreviations than NUREG-1640 and was written assuming that the Task 2 report would be published as a companion (this report makes reference to a "Volume II" that does not exist). In summary, this report contains important and relevant information, however, NUREG-1640 contains more complete and recent information on such topics as reuse and recycle of materials, metal industry practices, and refinery scenario parameter values.

1. INTRODUCTION AND SUMMARY

1.1 Background

After a nuclear facility ceases operation and completes decommissioning, its NRC license is terminated and the facility structures and lands are released for unrestricted public use. Currently, there are inconsistencies between NRR, NMSS, and individual state programs in the standards that are applied to the release of contaminated material. To address this, the NRC is currently assessing potential pathways of exposure resulting from unrestricted use of lands and structures (Kennedy, 1992) and is considering a rulemaking to codify criteria for acceptable levels of residual radioactivity for release of the structures and lands for unrestricted use.

When these nuclear facilities undergo decommissioning, there are large quantities of equipment, components, piping, etc., which remain and require disposition, some of which are contaminated with radionuclides. The levels of radioactive contamination in these materials vary from high levels, which require that the materials be managed and disposed of as waste at licensed disposal sites in order to protect the public and the environment, down to very low levels where the material does not present a significant risk to the public or the environment. Some of this material may be decontaminated and released for unrestricted use. Other material may have low enough levels of radioactivity that it could be released for unrestricted reuse without the need for decontamination. There may be an economic incentive to recycle or reuse this material in other products. Similarly, during normal facility operations, certain equipment, components, etc., may be released for unrestricted use and potentially recycled. Currently, small quantities of such equipment, components, etc., are released for unrestricted use during operations using the existing case-by-case criteria noted above.

In current practice, material which is contaminated with very low levels of radioactivity is normally classified as low-level radioactive waste and is disposed of in licensed burial grounds. The existing capacity of low level waste management systems in the US (burial grounds and storage systems) is extremely limited and progress on designating and siting new facilities very slow, the classification of some of this material from decommissioning as low level waste may not be an appropriate or optimum use of limited resources such as storage or disposal space, dollars, or material itself in cases where the waste material could be recycled or reused.

Because of the maturing of the nuclear industry and the potential for large scale decommissionings with large quantities of contaminated material, the NRC is conducting an overall reassessment of the potential radiological impact of release and recycle and/or reuse of equipment, components, materials, etc., during both decommissioning and normal facility operations. Such a reassessment includes an evaluation of both the doses and costs of alternative means for dealing with these materials. The NRC is assessing the nature and amount of these slightly contaminated

wastes and the impacts that would result if this material were to be made available for recycle or reuse. For this effort, this report uses the following definitions of recycle and reuse:

1) Recycle - conversion of materials (e.g., steel, copper, aluminum) present in components from a nuclear facility to form new products through normal industrial processes, which would then be available in the public sector;

2) Reuse - transfer of a functional component, system or material from a nuclear facility to some other application where it would then be used to carry out its original function;

3) Controlled recycle/reuse

   a) Controlled recycle - conversion of materials present in components from a nuclear facility to form new products through normal industrial processes that would be restricted in their use to nuclear facilities.

   b) Controlled reuse - transfer of a functional component, system or material from one nuclear facility to another for similar applications. As an example, the controlled reuse of a contaminated but operable pump would involve the transfer of the pump from facility A to facility B where it would continue to be used as a pump.

1.2 Purpose of this Report

The intent of this report is to provide background information to be used in selecting the appropriate set of pathway scenarios for assessing the health and safety impacts of the potential large-scale reuse and recycle of contaminated nuclear material. The pathway analysis is contained in Volume II of this report. The information presented in this report summarizes the results of an extensive literature search. If additional information needs are identified as part of the pathway assessment, then the literature search will be expanded to address these needs. Based on the extensive library of resources which has been compiled and personal contacts which have been established during the literature search, future information needs can be rapidly addressed.

This volume presents information in order to assess: current generation of contaminated nuclear material in the US as well as projections of future generation rates; disposal practices at low level waste (LLW) sites; current decontamination technologies and regulatory standards in the US and worldwide; as well as a summary of previous dose pathway assessments.

The information is presented in a set of stand-alone Chapters describing the relevant information to support the pathway analysis in Volume II. The Chapters focus in the following areas: (1) amounts of material available at nuclear facilities that are potentially available for recycle, (2) current disposition of this material in the existing licensed LLW disposal facilities, (3) summary of the various decontamination technologies that exist which have the potential for treating this material, (4) current commercial reuse and recycle efforts for both contaminated and

non-contaminated material in the US and worldwide; (5) current standards regarding the disposition of this material, and (6) previous dose assessment studies evaluating the disposition of this material. Chapters 2 - 7 provide the results of this review and Sections 1.3 - 1.8 provide a summary of those chapters.

Section 1.9 combines all of the information presented in Chapters 2 - 7 to provide a preliminary economic analysis of the potential benefits of disposal versus recycle. Note, these estimates contain a large amount of uncertainty, since they are based on raw estimates of material generation rates, unit disposal and decontamination costs, scrap value, and decontamination efficiencies.

1.3 Generation of Waste Materials and Equipment During Normal Operations and Decommissioning

Chapter 2 presents information on the amounts of waste material and equipment which are expected to be generated during the operation or decommissioning of both nuclear reactors and nuclear fuel cycle facilities. For reactors, information is also presented on the expected radionuclide content of this material and equipment. In general, the materials which are considered to have potential for reuse and recycle in nuclear reactor and fuel cycle facilities are: concrete, iron/steel, aluminum and copper.

There was no single source of information which contained all of the relevant material to accurately estimate the material volumes and radionuclide content of material described above. The information presented are best-estimates, based on a thorough literature search of activities carried out to support the US NRC, EPRI and several international organizations (e.g., Euratom, CEC). In some studies, information was presented as material volumes, while other studies referenced material masses. Conversion factors were developed for each type of material considered based on the available information. In the end, information from several different studies was combined to provide the best available estimate. All relevant sources are referenced and, in general, the data is considered to be accurate to within a factor of 2.

Section 1.3.1 summarizes the expected quantities of waste generated by nuclear reactors and fuel cycle facilities, and Section 1.3.2 discusses the quantities of waste materials from nuclear facilities that are potentially recyclable. Section 1.3.3 provides a forecast of the projected total annual volume of potentially recyclable material, based on current schedules for nuclear reactor license renewal. All information presented in the following sections are represented in volumetric units (m^3).

Chapter 2 discusses this information in more detail and also includes an estimate of the expected radionuclide content of this material.

1.3.1 Waste Generation

Low level waste (LLW) is generated at operating reactors and fuel cycle and non-fuel cycle facilities at the rate of about 50,000 cubic meters per year. Table 1-1 provides a breakdown of LLW generation for the years 1987 through 1989. This information was compiled by the NRC based on a detail review of the burial records of the three operating commercial burial grounds during the years 1987 through 1989 (USNRC, 1990b).

The table presents information on the amount of waste that was generated by the commercial nuclear power industry alone (represented by utilities and private industry) and by all generators (including academic institutions, hospitals, government and commercial generators). This table shows that the majority of the low level waste is generated by the nuclear power industry (utilities and the private industry) and most of the waste by volume is class A waste. Class A waste contains the lowest level of activity of all LLW (as defined by 10.CFR.61) and has the highest potential for reuse and recycle.

Table 1-1. Generation of Low Level Waste (LLW) By Industry and
Waste Category for the Years 1987 through 1989

Year	Volume of Class A LLW Generated by Utilities and Private Industry (m^3)	Total Volume of LLW Generated by Utilities and Private Industry (m^3)	Total Volume of LLW From All Generators (m^3)
1987	45,000	46,000	52,000
1988	35,000	36,000	40,000
1989	38,000	40,000	46,000

In addition to the operational waste, there will be waste materials and equipment generated during the decontamination and decommissioning (D&D) of licensed nuclear facilities. Estimates of the volumes of material that would be expected to be generated during the D&D of a reference large BWR and PWR have been estimated (Smith, 1979; Oaks, 1980; Elder, 1980) and these are summarized in Table 1-2. These volumes were derived by estimating the total mass of each type of material used in the construction of a reference BWR and PWR, and determining the distribution of material status in terms of activated, contaminated and clean material. This information was derived by combining the results of several different sources and is described in more detail in Section 2.2.2.1. It is estimated that the actual volumes that would be generated during a decommissioning project could vary as much as 100% from the reference values presented in the table. This variation would be due to

details of plant design (e.g., the use of liners or not), the quality of the maintenance of components used in a specific facility (which impacts the frequency and size of leaks), general housekeeping practice.

The estimated volumes of contaminated material that would be generated during the decommissioning of an individual fuel cycle facility is expected to be very small compared to a nuclear reactor and there are relatively few licensed fuel cycle facilities. For a typical fuel facility, it has been estimated that as much as 500 m^3 of equipment, piping, and ducting could potentially be recycled.

Table 1-2. Estimated Volumes of Concrete and Metal Associated with the Decommissioning of a Reference Large BWR and PWR

Material Category	Concrete Material Volume (m^3)		Metal Material Volume (m^3)	
	BWR	PWR	BWR	PWR
Activated	800	800	1,500	1,000
Contaminated	11,000	12,000	8,000	7,500
Clean	280,000	140,000	38,000	42,000
TOTAL:	292,000	153,000	47,500	50,500

1.3.2 Potential Volumes of Material for Recycle or Reuse

Some fraction of the routine LLW presented in Section 1.3.1 is expected to have potential for recycle or reuse. Table 1-3 provides estimates of the LLW volumes occurring during normal operations that could potentially be recycled. This estimate is based on an analysis of information compiled under the sponsorship of the Electric Power Research Institute (Daloisio, 1989) and the NRC (USNRC, 1981). Details of the development of these estimates of waste volumes and masses that could be recycled, based on the total metal content in the waste material, are presented in Chapter 2.

Table 1-3. Estimated Annual Volume of Waste With Potential for Reuse and Recycle Produced During Normal Operations for all BWRs, PWRs and Fuel Cycle Facilities

Waste Type	Annual Average Waste Volume (m³)		
	BWRs	PWRs	Fuel Cycle Facilities
Non Compacted Dry Active Waste	3,400	3,200	---
Secondary Side Large Components	200	100	---
Condenser Tubes	400	NA	---
TOTAL:	4,000	3,300	310

Table 1-3 indicates that approximately 7,000 m³/yr (2800 MT) of potentially recyclable material is generated during the normal operation of nuclear power plants. This number is roughly equivalent to the estimated volume of 4,000-5,000 MT/yr of contaminated material which was reportedly shipped from utilities to commercial scrap processors such as QUADREX and SEG (see Section 5.3). This indicates that the annual volume of potentially recyclable material generated during utility operations is approximately 10 percent of the annual LLW burial volume. Further, comparison of these numbers indicates that nuclear utilities currently recycle nearly all of this material to save money by avoiding LLW disposal costs. It is expected that the total potential volume of material in Table 1-3 could not be practically recycled or reused, because of problems such as radionuclide contamination levels and the effort required to sort and decontaminate the mixture of the recyclable materials. Based on reported scrap volumes from commercial processors generated by nuclear reactor operations, it is estimated that more than 80% of potentially recyclable contaminated metal scrap is sent by utilities to commercial processors (see Section 5.3 for further discussion).

Reference masses of metals that could potentially be recycled from the decommissioning of nuclear facilities, from both a large PWR and a large BWR have also been established and these are presented in Table 1-4.

Table 1-4. Estimated Volumes of Concrete and Metal Associated with Potential for Reuse and Recycle Produced During Decommissioning of a Reference Large BWR and PWR

Material Category	Concrete Material Volume (m³)		Metal Material Volume (m³)	
	PWR	BWR	PWR	BWR
Activated	800	800	1,500	1,600
Contaminated	11,700	10,800	7,600	6,700
TOTAL:	12,500	11,600	9,100	8,300

The numbers presented in Table 1-4 for potentially recyclable material are based on the material which was considered to be "Active" or "Contaminated" in Table 1-2. Comparison of the estimated total volume of concrete and metal from D&D presented in Table 1-2 with the potentially recyclable volume of each material in Table 1-4 shows that for steel, the recyclable portion is expected to be on the order of 20% of the total material volume, while for concrete the volume percentages of recyclable material are on the order of 5-15%.

Of the material reported as "Metal" in Table 1-4, more than 99% is expected to be steel with about 1% copper and about 0.01% aluminum. The latter materials are used primarily in cables and heat transfer materials.

1.3.3 Forecast of Annual Volume of Potentially Recyclable Material

This section provides a forecast of the total annual volume of potentially recyclable material that is expected to be generated, based on current schedules for nuclear reactor license renewal. Since the estimated volume of potentially recyclable material from fuel cycle facilities is more than an order of magnitude smaller than reactors, only reactor D&D material volumes are considered.

Currently, the vast majority of potentially recyclable material is generated during the normal operation of nuclear facilities, as there has been very little decommissioning activity to date. The expected volume of potentially recyclable material from D&D will become significant if several reactors are undergoing D&D at the same time. Table 1-2 shows the reference volumes of waste materials expected to be generated during reactor D&D. To illustrate, if it is assumed that three reactors were undergoing D&D at the same time and the duration of the D&D operation was about three years, the annual volumes of potentially recyclable material generated would be on the order of 20,000 m³/year which is approaching the current annual burials of LLW reported in Table 1-1.

assumed that three reactors were undergoing D&D at the same time and the duration of the D&D operation was about three years, the annual volumes of potentially recyclable material generated would be on the order of 20,000 m³/year which is approaching the current annual burials of LLW reported in Table 1-1.

If a large number of reactors undergo D&D at the same time (as is expected following the turn of the century), the annual volume of wastes generated would far exceed the current annual burials of LLW.

1.4 Disposal of Materials from Nuclear Facilities at LLW Sites

Chapter 3 discusses expected availability and costs associated with disposal of materials from nuclear facilities at licensed LLW disposal facilities. In the future, LLW disposal cost and availability are expected to strongly influence reuse and recycle practices.

Currently, materials from nuclear facility operations are disposed of at LLW sites at the rate of about 45,000 m³ per year (1.5 million ft³). The disposition of this waste is changing as a result of developments that are occurring in the waste disposal area. Today, the total volume of contaminated material which is potentially recyclable only represents about 10 percent of the annual LLW burial volume. This is expected to significantly increase in the future as large numbers of nuclear facilities undergo D&D.

Over the past few years there have been only three active low level disposal sites in the nation, but this number is decreasing. The Nevada disposal site was closed at the end of 1992 and the South Carolina site is scheduled to close January 1, 1996. In addition to the reduction in the number of operating sites, restrictions are being placed on the amount of waste that is received from other regions of the country. While many regions and states have plans to develop waste storage or disposal facilities, progress toward siting and designing such facilities is very slow. In many instances, there are no schedules for facility openings. The net result is that most waste generators are having to make plans to store LLW on their site until disposal or regional storage is possible.

It is very difficult to prepare cost projections for disposal of waste materials from nuclear facilities because the costs are strong functions of the annual waste volume that is handled and, in some cases, surcharges and fees that are placed on all or some of the waste that is handled. During the 1990s unit disposal costs are projected to range from $5,300 to $10,600 per m³ ($150 to $300 per ft³).

1.5 Decontamination Technologies

Chapter 4 provides an overview of various techniques and processes that might be used in decontaminating nuclear components, equipment and/or materials prior to disposal or recycle/reuse.

An extensive literature search was performed to identify all decontamination technologies that have been demonstrated to have potential applications to nuclear material. Decontamination processes can be classified as either surface decontamination processes or volume decontamination processes. Surface decontamination processes are generally either an abrasive or a high pressure cleaning process, or a chemical bath process. Volume decontamination processes are destructive in nature and generally involve either melting or electrical dissolution of the metal.

The various decontamination processes are summarized in tabular form in Chapter 4. For each of the processes identified, the table provides the following categories of information: a general description of the process, the materials or chemicals used in the process, typical decontamination factors (DFs), wastes produced by the process which ultimately require disposal, an example application of the process, any quantitative or qualitative cost data that was available, reference documents, and miscellaneous comments.

The DF is defined as the ratio of activity before and after the decontamination process. The total activity measured can be divided by either the mass or the surface area of the item being surveyed, giving units such as Bq/g or Bq/cm^2. As can be expected, the DF for a process was shown to be very specific to the type and composition of the material being removed. Certain common alloying agents (i.e., cobalt and nickel) tend to bond right into the metal during volume decontamination processing, while others that do not normally alloy tend to leave the metal as byproducts in the slag or dust. Because of these types of phenomena, the chemical properties of the contaminants need to be considered when selecting the appropriate decontamination technique. Chapter 4 provides a compilation of all laboratory and industrial-scale experiments that have been performed to characterize the behavior of contaminants for various decontamination processes.

Since there has not been a great deal of experience world-wide in decontaminating large amounts of nuclear-contaminated material, only limited data is currently available on expected waste volumes and costs associated with industrial-scale application of some decontamination processes.

1.6 Recycle of Metal in the United States and Worldwide

Chapter 5 describes current commercial recycle and reuse efforts for both non-contaminated and contaminated metals in the U.S. and worldwide for steel, copper, and aluminum. The information collected addresses both conventional recycle of non-contaminated material as well as current recycle practices for material from nuclear facilities in the U.S.

For the commercial recycle industry, copper, steel and aluminum were selected for examination, as they are the metals most commonly used in nuclear power plant construction. The information presented includes a discussion of: (1) overall domestic production and use, (2) structure of the scrap metal industry, (3) costs of recycle, and (4) recycle process steps. Chapter 5 also examines existing practices regarding recycle of slightly contaminated metals in the U.S. and worldwide, including estimated material flows for contaminated scrap processing.

The major points which can be drawn from the discussion in Chapter 5 are:

1) The extent of recycle for specific metals depends on the market value for the scrap metal and the general supply of the scrap. For low-valued high-volume metals such as iron or steel (scrap values of pennies per pound), there is recycle potential which tends to be of a local nature because the collection and hauling costs can easily become greater than the selling price of the scrap material. For such low-valued, high-volume metals not all of the scrap is recycled. In contrast, higher value metals such as copper and aluminum have very high recycle percentages because the collection and transportation costs are generally less than the selling price of the scrap metal at the recycle facility. For these metals, there are accumulations of these metals awaiting recycle.

2) At the present time, about 4,000 to 5,000 MT/year of material is recycled from licensed nuclear operations. Material with only surface contamination is released according to the limits in NRC Regulatory Guide 1.86. Material which has volumetric contamination is not released on an unrestricted basis but must go to a licensee or an organization that is exempt from licensing, such as the DOE. The recycling is performed primarily by two companies, SEG and QUADREX, both of which are licensed by the state of Tennessee. Most of the recycled material is carbon steel with smaller amounts of stainless steel or Inconel, copper alloys, and aluminum.

3) The mass of material potentially available for recycle from nuclear operations (on the order of a few tens of thousands of tons per year of steel, a few tens to hundreds of tons of aluminum and copper) are very small in comparison to the normal industrial recycle amounts. Old (post-consumer) iron and steel scrap is recycled at the rate of about 30 million metric tons per year, old copper scrap is recycled at the rate of about half a million metric tons per year, and old aluminum scrap is recycled at the rate of over one million metric tons per year. All of these flows are about three orders of magnitude greater than the potential contribution from nuclear facilities.

1.7 Standards for Recycle and Reuse in the United States and Worldwide

Chapter 6 provides a detailed summary of the current standards (both in the U.S. and worldwide) for the restricted and unrestricted release and potential recycle of contaminated material from nuclear facilities.

The review of this information has shown that there is variability from country to country in the nature of dose and activity standards for material with very low levels of contamination. Some countries have standards for both dose and activity while other countries have only one or the other. In addition, some countries have neither but have still been able to take action on specific cases by applying more generic national or international standards.

1.8 Previous Dose Assessment Studies for Recycle and Reuse

Chapter 7 reviews previous pathway studies that have been conducted to estimate the dose consequences of recycle and reuse of various contaminated materials. They include disposal pathways, incineration pathways, and recycle and reuse pathways for a variety of materials. One of the documents reviewed (IAEA, 1992) presented a comparison of the activity levels that would result in 10 uSv/yr for various scenarios as presented by various authors. These factors were reviewed and used in conjunction with information on the distribution of radionuclides associated with contamination of piping and concrete in reactors. Table 1-5 shows the distribution of radionuclides expected to be associated with reactor contaminated materials. The table shows that the major radionuclides are Mn-54, Fe-55, Co-60, Zn-65, Cs-134, Cs-137, and Ce-144.

1.9 Preliminary Economic Evaluation of Material Disposition

This section provides a preliminary economic analysis which compares the cost of LLW burial with the cost of decontamination of material and recovery of scrap value. Two material volumes are considered: (i) the estimated annual volume of contaminated steel generated during NRC-licensed operations; and (ii) the estimated volumes of contaminated materials generated during the decommissioning of a large (1000 MWe) PWR. Table 1-6 provides the results of the economic cost analysis.

The results presented in Table 1-6 are not intended to be precise estimates of the cost savings associated with recycle, rather they are intended to demonstrate that based on the current prevailing market the possibility for cost savings through the recycle of contaminated nuclear material does exist. As industry dynamics and operating practices change, the various cost estimates that were used to derive the numbers in Table 1-6 will change. As such, the use of these estimated cost savings for any long-term economic analysis is ill advised.

**Table 1-5. Comparison of Isotopic Distribution Expected for
Reactor Contaminated Piping and Concrete**

Radionuclide	Piping		Concrete (% Activity)
	Primary (% Activity)	Secondary (% Activity)	
Mn- 54	2.54	13.11	0.38
Fe- 55	69.96	81.92	12.29
Ni- 59	0.01	0.00	0.05
Co- 60	13.57	3.44	6.76
Ni- 63	1.70	0.16	0.30
Zn- 65	11.87	1.20	0.00
Sr- 90	0.01	0.01	0.01
Ag-110 m			0.11
Sb-125		0.03	0.00
Cs-134	0.06		19.06
Cs-137	0.12	0.07	22.75
Ce-144			38.11
Eu-152			0.06
Eu-154			0.04
Eu-155			0.02
Cm-242	0.15	0.07	0.05
TOTAL:	100.00	100.00	100.00

Table 1-6. Summary of Preliminary Cost Comparison for Disposal and Recycle of Contaminated Metal

	Estimated Annual Amount of Material from NRC-Licensed Operations	Estimated Amount of Material from the Decommissioning of a Large (1000 MWe) PWR			
Material	Steel	Steel	Copper	Aluminum	Concrete
Total Value (m³)	7,300	7,000	430	13	12,000
LLW BURIAL OPTION					
Unit LLW Burial Cost ($/m³)	7,063	7,063	7,063	7,063	7,063
Estimated Burial Cost ($)	52,000,000	49,000,000	3,000,000	94,000	85,000,000
DECONTAMINATION AND SCRAP RECYCLE OPTION					
Unit Decon Cost ($/m³)	350	350	500	460	600
Calculated Decon Cost ($)	2,550,000	2,450,000	215,000	6,000	7,200,000
Decontamination Yield (%)	85%	85%	85%	85%	85%
Scrap Volume (m³)	6,200	6,000	365	11	10,200
Burial Volume of Decontamination Waste (m³)	1,100	1,000	65	2	1,800
Decon Waste Burial Costs ($)	8,000,000	7,000,000	450,000	14,500	12,700,000
Unit Scrap Value ($/m³)	420	420	1,500	500	0
Calculated Scrap Value ($)	2,600,000	2,500,000	550,000	5,500	0
Estimated Cost (Revenue) Associated with Recycle*	8,000,000	7,000,000	115,000	15,000	20,000,000
Cost Saving Associated with Recycle	44,000,000	42,000,000	2,885,000	79,000	65,000,000

* (Decontamination Cost) + (Waste Burial Cost) - (Scrap Value)

The cost implications of disposal and recycle are a function of material generation rates, unit disposal costs, unit decontamination costs, scrap value and decontamination efficiencies. Each of these parameters was estimated for the purpose of the cost analysis based on currently available information and trends. The estimated material volumes for each case are derived from Section 1.3 and Chapter 2, the unit LLW burial cost estimate of $7063/m^3 is based on information in Chapter 3, the unit decontamination costs and unit scrap are estimates based on the latest available information from US contaminated scrap recyclers as discussed in Chapter 5. For mass-to-volume material conversions the following values were used: concrete (1.2 MT/m^3), steel and copper (0.7 MT/m^3), aluminum (0.3 MT/m^3).

The following inferences can be made based on the results in Table 1-7:

- There is a significant cost associated with LLW disposal.

- Recycle of material is still expected to cost money (i.e., decontamination cost exceeds scrap value) but the costs are expected to be significantly less than those associated with LLW disposal.

- The cost savings associated with the recycle of material is potentially very large.

While the table does not address it specifically, it does show that material which is noncontaminated when it is removed from the plant could be recycled and possibly generate revenue.

In addition to economic implications of recycle or reuse, there are other potential benefits which include energy savings, as well as reduced fatalities and injuries due to reduced material processing. Risks associated with material processing can occur as a result of construction accidents which occur as a result of the processes and can also occur as a result of transportation of materials on U.S. highway systems. These are nonradiological risks and estimates of the risks can be taken from construction and transportation industry statistics. Examination of these benefits is expected to occur at a later date when pathway studies have been completed and there are estimates of the doses associated with disposal and recycle/reuse.

2. GENERATION OF WASTE MATERIALS AND EQUIPMENT DURING NORMAL OPERATIONS AND DECOMMISSIONING

2.1 Introduction

The purpose of this chapter is to present information on the slightly contaminated equipment and materials that are expected to be generated during normal operations and decommissioning at NRC-licensed facilities, which have the potential for being reused or recycled. The presentation is organized into two major sections that are based on facility types - Section 2.2 is devoted to nuclear reactors and Section 2.3 to nuclear fuel cycle facilities. For reactors, information is also presented on the expected radionuclide content of this material and equipment. In general, the materials which are considered to have potential for reuse and recycle in nuclear reactor and fuel cycle facilities are: concrete, iron/steel, aluminum and copper.

There was no single source of information which contained all of the relevant material to accurately estimate the material volumes and radionuclide content of material described in this chapter. The information presented are best-estimates, based on a thorough literature search of activities carried out to support the US NRC, EPRI and several international organizations (e.g., Euratom, CEC). In some studies, information was presented as material volumes, while other studies referenced material mass masses. Conversion factors were developed for each type of material considered based on the available information. In the end, information from several different studies was combined to provide the best available estimate. All relevant sources are referenced and, in general, the data is considered to be accurate to within a factor of 2.

2.2 Nuclear Reactors

Information is reviewed regarding the amount of material and radionuclide contamination level that is generated and may be recycled during normal operations (Section 2.2.1) and during decommissioning (Section 2.2.2).

2.2.1 Normal Operations of Reactors

2.2.1.1 Volumes and Masses of Waste Material and Equipment

The operation of nuclear power reactors results in the generation of a variety of wastes, including protective clothing, contaminated tools and equipment, filters, irradiated metals, fittings, valves, wood, paper, and plastic. The amount of these materials produced at a reactor varies depending on the current operating status of the

reactor (major outage versus normal full power operation), the details of the reactor support systems such as the waste treatment systems, and the type of reactor (PWR versus BWR).

One source of information on this waste material is the Electric Power Research Institute (EPRI) which, as part of a research effort to support a rulemaking petition for Below Regulatory Concern (BRC), identified and evaluated several different waste streams produced at nuclear power plants which were potential candidates for exemption from low-level waste disposal requirements. Of twelve waste streams that were identified, three were identified as potentially attractive from a reuse or recycle viewpoint (Dalosio, 1989). These three waste streams were:

- non-compacted dry active waste (DAW): material and small components such as tools, conduit, pipes, valves, fittings, and other scrap material which is not normally compacted before disposal as radwaste;

- secondary side large components: any large pieces of equipment (not considered non-compacted DAW) from the steam and condensate systems (secondary side) of both BWRs and PWRs, which typically contain very low levels of surface or volumetric activity. Examples include feedwater heaters, piping, condensate pumps, etc.;

- condenser tubes: low activity tube bundles resulting from the replacement of BWR condenser tubes.

The volumes and mass associated with these three equipment categories which EPRI identified as having potential for reuse or recycle are presented in Table 2-1. The table shows that the non-compacted dry active waste stream has a much larger volume than the other two and there is variation in the volume of the non compacted dry active waste stream with reactor type. The waste volumes for secondary side large components and condenser tubes were converted to a mass basis using a nominal burial density of 700 kg/m^3 (obtained from PNL estimates of burial volumes of metallic waste from the decommissioning of PWRs and BWRs). For non-compacted dry active waste, a nominal density of 350 kg/m^3 was used based on an estimated scrap yield of 50 percent.

Table 2-1. Reference Annual Volumes of Wastes with Potential for Reuse and Recycle Produced During Normal Operations by a Typical PWR and BWR.

Waste Type	Annual Average Waste Volume from a PWR		Annual Average Waste Volume from a BWR	
	(m^3)	(MT)	(m^3)	(MT)
Non Compacted Dry Active Waste	41.9	14.6	90.6	31.7
Secondary Side Large Components	1.4	1.0	5.7	4.0
Condenser Tubes	N/A	N/A	10.8	7.5

The volume estimates were checked against other estimates of these waste streams. The EPRI non-compacted dry active waste volume estimate was compared against an earlier estimate prepared by the NRC in the Draft Environmental Impact Statement (EIS) for the rulemaking in 10 CFR 61 (USNRC, 1981). That document presented an estimate for non-compactible trash that was on the order of 105 to 110 cubic meters per year for an average 1000 MWe LWR. (These estimates were not revised in the Final EIS for the 10 CFR Part 61 rulemaking). Waste classified as non-compactible trash is generally non-combustible and has a high percentage of metallic components. These include irradiated reactor internals such as filters, instrumentation, tools, and miscellaneous equipment. As such, it is considered to be comparable to EPRI's designation of non-compactible dry active waste. Although NRC estimates are about a factor of two larger than the EPRI estimate for the PWR and about the same for the BWR, this difference is not considered significant given the uncertainty in these types of estimates and the expectation that there would be some decrease over the years as a result of industry efforts to minimize waste generation due to increases in waste disposal costs.

Using the reference volumes for potentially recyclable material in Table 2-1 and considering the total population of operating reactors (77 PWRs, 37 BWRs), the estimated annual volume of such waste produced during normal operations is 2,800 MT (7,000 m^3). These numbers indicate that roughly 60% of the 4,000-5,000 MT of metal which is sent by nuclear utilities to contaminated scrap recyclers such as QUADREX each year (see Section 5.3). About 85-90% of the material processed is sold as commercial scrap with the remaining 10-15% being sent to licensed LLW disposal sites.

2.2.1.2 Radionuclide Content of Waste Material and Equipment

The only source of information on contamination levels and distribution of nuclides for non-compacted dry active waste (uncompacted trash) was the NRC DEIS for the 10 CFR Part 61 Regulations (USNRC, 1981). This information is presented in Table 2-2. The major nuclides were Co-60, Cs-137, and Fe-55. Comparison of total activity levels shows BWR contamination levels are expected to be significantly higher than those associated with PWRs.

Information on contamination levels and radionuclide distribution for secondary side components and condenser tubes was found in a report by PNL (Abel, 1986). Information from this report is presented in Table 2-3. The table shows there are large variations in contamination levels. On the average, the major radionuclides are Fe-55, Mn-54, and Co-60.

It should be noted that concentration levels presented in Tables 2-2 and 2-3 provide a statement of the relative abundance of various isotopes as they are presented in material as it is removed from the plant. From a public health and safety point of view, the significance of these results depends on how this material is processed and ultimately disposed of afterwards. This is the very subject of the dose pathway assessment studies in Volume II of this report.

Table 2-2. Level of Activity and Distribution of Radionuclide Contaminants Associated with Non-compacted Trash

| Radionuclide | NRC Non-compacted Trash | |
	PWR (% Activity)	BWR (% Activity)
H-3	1.33	0.29
C-14	0.05	0.02
Mn-54	0.00	0.00
Fe-55	26.13	25.60
Ni-59	0.03	0.03
Co-58	0.00	0.00
Co-60	50.55	42.79
Ni-63	9.63	0.58
Sr-90	0.10	0.05
Nb-95	0.00	0.00
Zr-95	0.00	0.00
Ru-106	0.00	0.00
Ag-110 m	0.00	0.00
Sb-125	0.00	0.00
Cs-134	0.00	0.00
Cs-137	11.03	30.38
Pu-238	0.03	0.01
Pu-239 240	0.02	0.00
Pu-241	1.06	0.24
Cm-244	0.01	0.01
Total Activity Ci/m^3	.525	3.79

Table 2-3. Concentration Ranges, Averages, and Distribution for
Radionuclides in Corrosion Films Internally
Deposited in Piping and Hardware Exposed to
Liquid Radwastes and Secondary Coolant

Radionuclide	Concentration Range (pCi/cm^2)		Average Concentration (pCi/cm^2)	Distribution of Activity (%)
Mn-54	2	- 4.70 x	160,000	13.11
Fe-55	710	10^5	1.0 x 10^6	81.92
Co-60	64	- 7.1 x 10^6	42,000	3.44
Ni-59	0.63	- 2.74 x	6.2	0.00
Ni-63	3	10^5	1,900	0.16
Zn-65	<0.4	- 15	14,600	1.20
Sr-90	<0.00	- 10,000	88	.01
Nb-94	9	- 27,400	--	--
Tc-99	<0.1	- 260	--	--
Sb-125	<0.05	- 100	420	.03
I-129	9.3	- 0.2	--	--
Cs-134	<0.00	- 1,200	--	--
Cs-137	06	- 0.9	860	.07
Ce-144	<0.3	- 1,900	--	--
Pu-238	<0.6	- 4,000	7.4	0.00
Pu-239 240	<0.6	- 2,000	3.6	0.00
Am-241	0.0014	- 51	7.3	0.00
Cm-242	0.0012	- 24	820	0.07
Cm-244	0.0009	- 41	12	0.00
	0.0013	- 3,600		
		- 58		

2.2.2 Decommissioning of Reactors

2.2.2.1 Volumes and Masses of Waste Material and Equipment

<u>Pressurized Water Reactor (PWR)</u>

In a PWR, heat is transferred from the reactor pressure vessel to a heat exchanger by water kept under high pressure in order to achieve high temperature without boiling in the primary system. Steam is generated in the secondary circuit. The steam is used to drive the turbine to produce electricity. Fuel for the PWR is slightly enriched uranium dioxide (UO_2) in rod form, encased in zircaloy cladding. The design and manufacture of the PWR fuel is such that is has a very low potential for leakage. In addition, primary coolant system water is treated to reduce radiation exposure to workers.

Nevertheless, at the end of a reactor's operating life, various components in the reactor primary coolant system will have different types and levels of radionuclide contamination. The material that is very near the reactor core (the reactor pressure vessel and internal components, the piping within the biological shield, and the materials that form the biological shield) will have undergone neutron irradiation during the operating life of the reactor and as a result will contain activation products distributed throughout these materials. This material is referred to as activated equipment and has radioactive isotopes throughout the material volume, not just on the surface.

Components, equipment, and piping throughout the facility can have surface contamination as a result of the deposition of radionuclides on their internal surfaces. Contamination associated with the primary system components and piping and with other systems in contact with the primary system, such as the auxiliary system or radwaste system, would contain radionuclides from any leaking fuel or from activation of corrosion products present in the water within the reactor vessel. This contamination deposits on the equipment and piping surfaces. Contamination levels on piping and equipment in the secondary cooling system is generally significantly lower due to the heat exchange barrier. This material is referred to as contaminated and has varying levels of radioactivity, depending on the facility. This equipment can be decontaminated to reduce the levels of radioactivity. Certain components in certain systems in a reactor (i.e., circulating water, service water, etc.) do not come into contact with any radioactivity and are referred to as "clean."

When the reactor is decommissioned, all the equipment, components, and piping are removed and the structure is demolished. An estimate was made of the materials associated with the decommissioning of a large PWR. This estimate was based primarily on an ORNL study (Bryan, 1974) which presented a listing of materials in a PWR and provided information on the distribution of these materials throughout the major plant systems. The

ORNL report did not, however, identify material at the component level. A second source of information was a PNL study on the decommissioning of a large PWR (PNL, 1985). This report identified some of the major components of a reactor that would be contaminated, but it did not identify all of the materials in a PWR. Comparisons of information in the two reports were made where possible. Such comparisons are considered to be indicative of the variability that can be expected between individual plants. As an example, the ORNL report identifies about 3,600 MT of steel in reactor building equipment while the PNL report identifies about 2,800 MT. Only the PNL report provides details on the major components contributing to the mass. The major components and their mass are reactor vessel and head, 400 MT; steam generators (4), 1,250 MT; coolant pumps (4), 340 MT; and piping, 600 MT. The comparisons of concrete in the reactor building are more difficult. The ORNL report estimates 54,000 MT of concrete associated with the reactor building which includes the containment structure, while the PNL report identified about 13,000 MT, but this PNL estimate was only for structures within containment. Table 2-4 provides an estimate of the total mass of material within a large PWR with the information drawn largely from the ORNL report which addressed the entire PWR facility.

Table 2-4. Mass of Major Materials in a Typical Large (1000 MWe) PWR

Plant Area	Mass of Concrete (MT)	Mass of Steel (MT)	Mass of Copper (MT)	Mass of Aluminum (MT)
Reactor Building and Equipment	55,000	12,000	60	5
Auxiliary Building and Equipment	34,000	1,500		
Fuel Building and Equipment	7,000	500		
Turbine Building and Equipment	31,000	13,000	52	1
Control Building	17,000	2,000		6
Main Cooling System (Canals or Tower)	28,000	2,500		
Electrical Plant	1,300	1,000	560	4
Total*	180,000	35,000	700	18

* Includes materials from plant areas other than the major ones identified in the table

An estimate was also made of the general contamination status of this material at the time of reactor decommissioning. For these estimates, the primary source of information was the PNL report along with a Euratom report (Group of Experts) and a CEC report (Charles, 1992). The material was grouped into three broad categories: (i) activated material which would come from the reactor core region, (ii) contaminated material which would cover material with surface contamination at levels above free release, and (iii) clean material which should be uncontaminated. The contaminated material would be equipment which contained the primary coolant, the rad waste systems, and areas where there were leaks or spills. Table 2-5 provides a summary of the expected waste masses produced during the decommissioning of a typical PWR. While individual reactors are expected to vary from these reference values because of design and operational specifics at each plant, this distribution of material status is considered to be typical.

Table 2-5. Reference Waste Masses Produced During the Decommissioning of a Typical PWR

Material Category	Concrete (MT)	Steel (MT)	Copper (MT)	Aluminum (MT)
Activated	1,000 (0.5%)	1,000 (3%)	0	0
Contaminated	14,000 (7.5%)	5,000 (14%)	300 (43%)	4 (22%)
Clean	165,000 (92%)	29,000 (83%)	400 (57%)	14 (78%)
Total	180,000	35,000	700	18

Boiling Water Reactor (BWR)

In a BWR, water is used as both coolant and moderator and is allowed to boil in the core. The steam from the reactor is dried and then used to drive the turbine to produce electricity. The designs of a boiling water reactor core are similar to those of pressurized water reactor. BWR fuel is also UO_2 in rod form with zircaloy cladding, and is designed and manufactured to have low leakage potential. Contamination at a BWR is caused in the same manner as at a PWR, resulting in activation of equipment and deposition of radioactive by-products on the equipment and component surfaces.

In many areas the design of a BWR is comparable to that of a PWR. Systems which are included at both types of plants are expected to have higher levels of radioactive contamination in a BWR because this equipment has

routine contact with radionuclides during the operating life of the plant. The basic design of the electrical plant would not be expected to change based on the style of the reactor. The turbine plant equipment and the instrumentation and control equipment is basically made up of the same types and quantities of materials regardless of the style of the reactor.

No report was found which listed the major materials in a large BWR. A series of reports which presents capital cost estimates for various electric generating plants was used to help estimate material amounts. The eighth update of this Energy Economic Data Base Program involved a report for DOE (DOE, 1986) which addressed a large PWR and a report for NRC (NRC, 1986) which addressed a large BWR. These reports provide a basis for making some comparison between large PWRs and BWRs. The reports show that a BWR requires significantly more concrete and slightly less steel than a PWR. This information, together with information from a PNL report on BWR decommissioning (Oak, 1980), was used to estimate the mass of major materials in a BWR. These are presented in Table 2-6. The increase in the quantity of concrete needed is a result of the direct cycle system requiring a larger biological shield. The reduction of the amount of steel is due to the direct cycle system not having a steam generator in its cooling loop.

Table 2-6. Estimated Mass of Major Materials in a Typical Large (1000 MWe) BWR

Plant Area	Mass of Concrete (MT)	Mass of Steel (MT)	Mass of Aluminum (MT)
Reactor Building and Equipment	100,000	11,000	1
Turbine Building and Equipment	110,000	9,500	38
Control Building and Equipment	64,000	3,500	19
Miscellaneous	75,000	8,500	0
Total	350,000	32,500	58

Estimates were also made of the contamination status of this material at the end of reactor life. These estimates are based primarily on the information presented in the PNL decommissioning study (Oak, 1980) and are presented in Table 2-7.

**Table 2-7. Reference Waste Masses Produced During the Decommissioning
of a Typical Large (1000 MWe) BWR**

Material Category	Concrete (MT)	Steel (MT)
Activated	1,000	1,100
Contaminated	13,000	4,700
Clean	334,000	26,700

While the previous discussion has presented reference masses for a large PWR and a large BWR, it must be recognized that reactor design within this country has not been standardized to any significant extent. There is significant variation in plant layout and component size for plants of similar type. Consequently, there are variations in the amounts and types of materials used at a reactor site.

Additional variability is expected to be associated with the estimates of status of material at the end of plant life. The levels of contamination will be a function of design features as well as component performance and operating practice. The variations in design was previously mentioned and the variations of component performance could lead to variations in the number of leakage incidents and the number of maintenance operations which would be expected to be related to the extent of contamination. Variations in operating practice can affect housekeeping practices, which can result in varying levels of contamination.

As can be seen from Tables 2-5 and 2-7, BWRs and the PWRs produced roughly the same types and quantities of waste masses during decommissioning. This is consistent with the estimates of contaminated material that is reported in CEC publications (Charles, 1992 and CEC, 1988).

2.2.2.2 Radionuclide Content of Waste Material and Equipment

Because of the variability in contamination levels in PWRs and BWRs at the end of reactor life, only one presentation of information is made concerning types and levels of contamination. This information was drawn from a PNL report which measured contamination in various PWRs and BWRs. This report examined contamination in primary coolant systems, secondary coolant systems and concrete.

This investigation showed that the most abundant isotopes associated with primary and secondary reactor piping and hardware are expected to be Mn-54, Fe-55, Ni-63, and Co-60. Zn-65 was present in significant amounts on the corrosion film in BWRs. There can also be traces of transuranic elements such as plutonium, curium, and americium. The level and makeup of the radioactive contamination is expected to be quite variable from plant to plant based on the analysis that was performed of selected nuclear plants (Abel, 1986; p. 16). The information on the distribution of radionuclides found in primary and secondary piping and hardware is presented in Tables 2-3 and 2-8.

The investigation also examined the expected distribution (based on percent total activity) of radionuclides among primary and secondary piping and hardware. The majority (an estimated 75 to 95 percent) of the radionuclide contamination is expected to be in the steam generators while the second major source of contamination (an estimated 5 to 10 percent) is expected to be in the radwaste area (Abel, 1986). Table 2-9 presents this data for three PWRs.

Concrete associated with the bioshield and the sump area directly under the reactor vessel will be subject to neutron irradiation. Concrete that is subject to spills will also be contaminated. The distribution of radionuclides associated with contaminated concrete is presented in Table 2-10 (Abel, 1986). The table shows that the dominant radionuclides are expected to be Fe-55, Cs-134, Cs-137, and Ce-144.

Table 2-8. Concentration Ranges, Averages, and Distribution for
Radionuclides in Corrosion Films on Piping Exposed to Primary Coolant

Radionuclide	Concentration Range $(\mu Ci/cm^2)$		Average Concentration $(\mu Ci/cm^2)$	Distribution of Activity (%)
Mn-54	0.028	- 4.4	1.2	2.5
Fe-55	0.039	- 149	33	70.0
Co-60	0.16	- 23	6.4	13.6
Ni-59	$<5 \times 10^{-5}$	- 2.6×10^{-2}	6.6×10^{-3}	-
Ni-63	0.003	- 1.3	0.80	1.7
Zn-65	0.0005	- 5.8	5.6	11.9
Sr-90	$<3 \times 10^{-5}$	- 8.4×10^{-3}	3.2×10^{-3}	
Nb-94	$<1 \times 10^{-5}$	- 5.0×10^{-4}	2.2×10^{-4}	
Tc-99	4.5×10^{-6}	- 5.6×10^{-4}	1.5×10^{-4}	
I-129	$<1 \times 10^{-6}$	- 4.3×10^{-6}	1.4×10^{-6}	
Cs-134	0.019	- 0.046	0.030	0.06
Cs-137	0.003	- 0.17	0.056	0.12
Pu-238	2.4×10^{-6}	- 4.5×10^{-3}	1.1×10^{-3}	
Pu-239 240	1.5×10^{-6}	- 4.4×10^{-3}	9.8×10^{-4}	
Am-241	1.8×10^{-6}	- 8.3×10^{-3}	1.8×10^{-3}	
Cm-242	7.2×10^{-6}	- 2.4×10^{-1}	0.072×10^{-2}	0.15
Cm-244	2.2×10^{-6}	- 2.5×10^{-3}	6.8×10^{-4}	

Table 2-9. Distribution (%) of the Radionuclide Inventory Estimates for Three Pressurized Water Reactors

	Turkey Point-2	Indian Point-1	Rancho Seco
Steam Generators	89	77	94
Pressurizer	0.5	0.5	0.33
RCS Piping	0.9	2.6	0.71
Piping (Except (RCS)	<0.01	14	<0.01
Secondary System	0.1	0.2	0.05
Radwaste	9.2	7	5

Table 2-10. Concentration Ranges, Averages, and Distribution for Radionuclides Associated with Concrete from Highly Contaminated Areas Within Selected Nuclear Generating Stations

Radionuclide	Concentration Range (pCi/cm^2)	Average Concentration (pCi/cm^2)	Distribution of Activity (%)
Mn-54	35 - 21,000	6,200	0.4
Fe-55	2,200 - 830,000	200,000	12.3
Co-60	590 - 460,000	110,000	6.7
Ni-59	30 - 2,400	860	
Ni-63	3,100 - 6,400	4,800	0.3
Sr-90	1.6 - 480	170	
Nb-94	<3 - 50	--	
Tc-99	0.27 - 2.4	1.6	
Ru-106	<30 - 190	--	
Ag-110m	59 - 3,600	1,800	0.1
Cs-134	70 - 1.7 x 10^6	310,000	19.1
Cs-137	550 - 2.0 x 10^6	370,000	22.8
Ce-144	26 - 3.1 x 10^6	620,000	38.2
Eu-152	9 - 3,100	1,000	0.1
Eu-154	90 - 1,500	680	
Eu-155	10 - 500	260	
Pu-238	0.025 - 48	14	
Pu-239 240	0.089 - 21	7.7	
Am-241	0.10 - 30	8.7	
Cm-242	0.06 - 1,800	880	
Cm-244	0.05 - 52	13	
Np-237	0.013 - 0.26	0.016	

2.3 Fuel Cycle Facilities

Equipment, components, and waste materials that have the potential for reuse and recycle are also generated by the fuel cycle facilities that support reactor operations. These facilities include the fuel conversion facilities and the fuel fabrication facilities. The total generation of recyclable material volumes from these facilities is expected to be less than those from reactors because they are smaller in size and fewer in number. There are, as of 1993, two uranium conversion facilities and six fuel fabrication facilities in the United States.

2.3.1 Normal Operations of Fuel Facilities

While no direct estimates were identified for fuel cycle industry generation of equipment, components, etc. with high reuse or recycle potential, the NRC has previously estimated that about 15.5 m^3/GWe-year of non-process, non-combustible waste was generated by the nuclear fuel fabrication industry during normal operation (NRC, 1981). Given the current annual U.S. nuclear power generation rate of about 66 GWe (EIA, 1991), this results in an annual estimate of about 1,000 m^3/year. Because this estimate is for all non-process, non-combustible waste, it is expected to be a high estimate of the actual material that is a candidate for reuse or recycle from these facilities. It is estimated that less than 25% of this annual volume has both low levels of contamination and involves material that could be reused or recycled. If this estimated volume is used in conjunction with a nominal material density of 700 kg/m^3, a value representative of the average density of metallic waste that is buried from the D&D of a reactor (Oak, 1980; Smith 1979), the total estimated mass is on the order of 175 MT/year (250 m^3/yr) for the total population of fabrication facilities.

NRC also estimated that the total volume of waste generated from fuel conversion facilities was 9.6 m^3/GWe-yr (NRC, 1981). Using the same annual power generation rate, this results in an estimated annual volume of about 630 m^3/year. As with the previous NRC estimate, this is considered to be a high estimate of the amount of material available for reuse or recycle. As part of its license renewal, Sequoyah Fuels Corporation estimated its annual generation rate for contaminated equipment to be about 30 m^3 per year (SFC, 1992). If this estimate is applied to both U.S. conversion facilities, the total volume of material with very low levels of contamination would be on the order of 60 m^3/year, or about ten percent of the NRC estimate of the total LLW generated from such facilities. SFC presented no mass estimate along with the volume estimate. Assuming the same nominal density of 700 kg/m^3 which was used above, this corresponds to an annual mass of 42 MT/year.

This analysis indicates that the total amount of metallic material that is being generated by the nuclear fuel cycle facility operations, with the potential for reuse or recycle, is on the order of 200 MT/year (310 m^3/yr).

2.3.2 Decommissioning of Fuel Facilities

Equipment, components, etc. with very low levels of contamination are produced during facility operations. Similar to reactors, when a fuel cycle facility is decommissioned, the equipment, components, piping, etc. are dismantled and are available for potential recycle and reuse. This can result in material with very low levels of contamination being produced during facility decommissioning. Based on an earlier study which estimated the waste that would be generated during the decommissioning of a uranium fuel fabrication facility (Elder, 1980), it is estimated that as much as 500 to 600 MT of equipment, piping, and ducting could be recycled if it could be adequately decontaminated.

It is estimated that a similar mass would be associated with the decommissioning of a uranium conversion facility.

3. DISPOSAL OF MATERIALS FROM NUCLEAR FACILITIES AT LLW SITES

3.1 Current and Projected Status of Commercial Low Level Waste Disposal/Storage Capacity

3.1.1 Introduction

The equipment, components, and materials generated during normal operations and decommissioning of nuclear facilities may potentially be released for unrestricted use and be available for recycle. Alternatively, it may be found to be unacceptable for such release and must instead be disposed of at licensed low level waste (LLW) disposal sites.

The purpose of this chapter is to present information on the current availability and cost of commercial LLW disposal to support future cost/benefit analysis of various disposal alternatives. With the exception of describing the material acceptance criteria for individual facilities, this chapter does not attempt to characterize the content of LLW or develop insights about scrap recycle flow. These issues are addressed in Chapters 4, 5 and 6.

In the future, LLW disposal cost and availability will drive reuse and recycle practices. Today, the reuse and recycle of contaminated materials from nuclear facilities does not influence LLW cost/availability to any great extent, as potentially recyclable material only represents about 10 percent of annual LLW burial volume. If large numbers of nuclear facilities were to undergo D&D, however, this would have a significant impact on LLW disposal volume, as well as availability and cost of disposal.

Historically, expansion of LLW disposal capacity and the associated costs have been very volatile due to a number of political and economic influences. As a result, the capacity forecasts and cost estimates presented in this section should be understood in this context. To the greatest extent possible, the main influences which impact the cost and capacity estimates will be identified and discussed; however, no attempt is made here to project what future costs will be.

3.1.2 Background

The Low-Level Radioactive Waste Policy Act of 1980, as amended by the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA), made States responsible for the disposal of commercial low-level radioactive waste generated within States' borders. The LLRWPAA provides the framework for States to establish

the LLW management and disposal capacity needed for their LLW, and encourages States to form compacts for management of LLW by maintaining that the disposal of LLW can be most effectively carried out on a regional basis. The LLRWPAA ensured that the LLW disposal facilities operating when the Act was passed remained open through the end of 1992.

The LLRWPAA also set up a system of milestones, incentives, and penalties to promote steady progress of States towards development of LLW disposal capacity. The critical milestone of January 1, 1993 has already been reached, when the LLW disposal facilities operating when the LLRWPAA was passed in 1985 are no longer obligated to accept LLW from outside their State or Compact. Therefore, beginning in 1993, some States will not have a disposal site for the LLW generated within their borders, and storage at the point of generation will begin to be a more widely used management practice for LLW.

Since 1985, States have been engaged in activities to form regional compacts and to establish new LLW disposal capacity. Currently, there are nine Compact regions totalling 42 States that have operating LLW disposal facilities or plans to establish new LLW disposal facilities. There are also five States that are unaffiliated with a compact that have plans to establish new LLW disposal facilities on their own. There are five States/Jurisdictions that are not currently affiliated with a compact that do not have plans to construct a new LLW disposal facilities. Figure 3-1 shows the current alignment of States and Compacts for LLW disposal. Of the Compacts or States with plans to establish new facilities, four complete license applications have been prepared and submitted to the appropriate regulatory authorities.

The following sections summarize the development of LLW disposal capacity and the progress of States under the LLRWPAA as of January 1, 1993.

3.1.3 Compact Regions with Currently Operating Disposal Sites

Following the passage of the LLRWPAA in 1985, three Compacts were formed, comprised of 19 States, that included the three operating disposal facilities at Barnwell, SC, Beatty, NV, and Richland, WA. According to the LLRWPAA, as of January 1, 1993, these three Compacts are no longer obligated to accept LLW for disposal from outside the Compact.
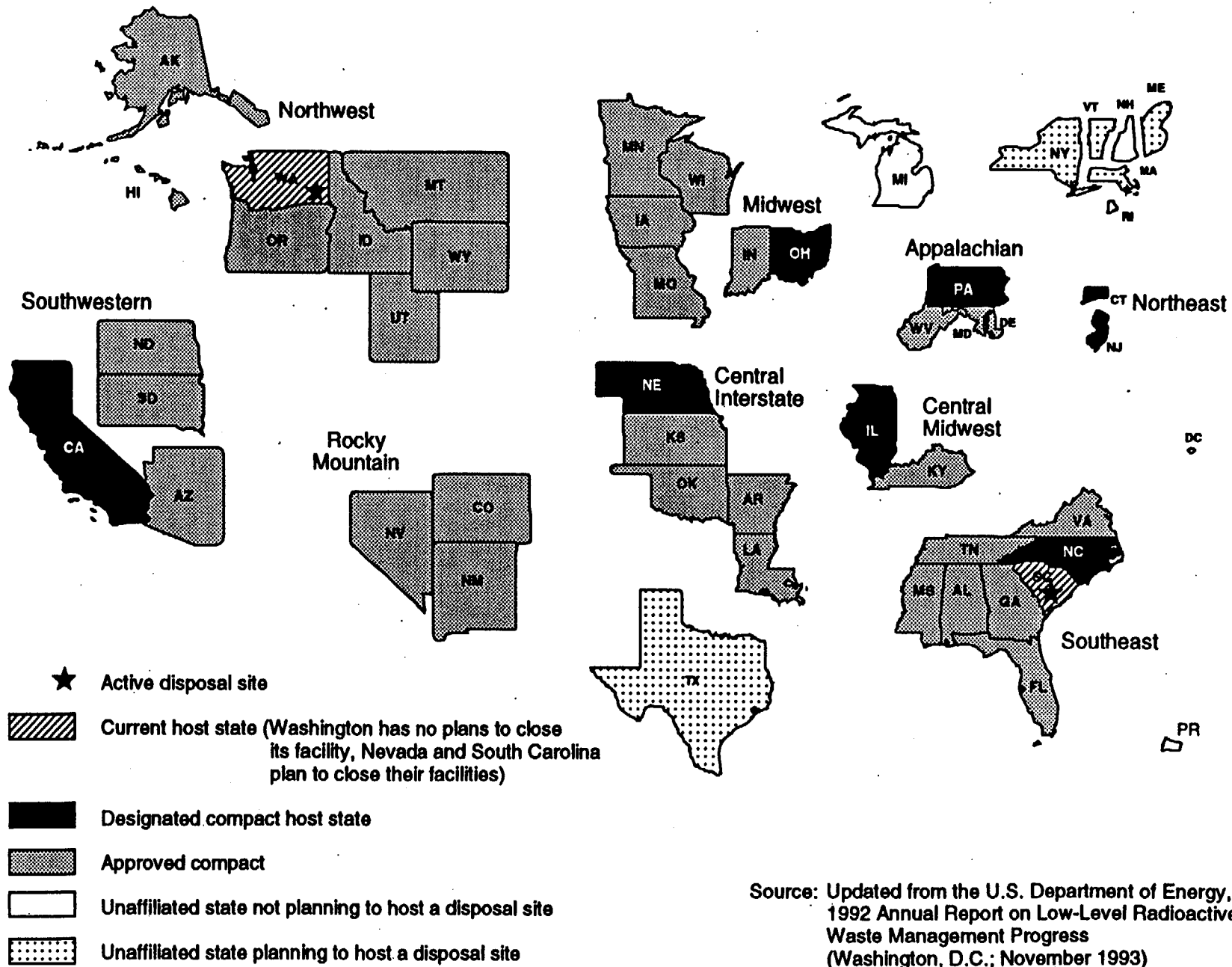
Northwest

Southwestern

Rocky
Mountain

Midwest

Appalachian

CT Northeast

Central
Interstate

Central
Midwest

DC

Southeast

PR

★ Active disposal site

Current host state (Washington has no plans to close
its facility, Nevada and South Carolina
plan to close their facilities)

Designated compact host state

Approved compact

Unaffiliated state not planning to host a disposal site

Unaffiliated state planning to host a disposal site

Figure 3-1. Current Configuration of Compact Regions/Host States and Unaffiliated States

3.1.3.1 Northwest Interstate Compact on Low-Level Radioactive Waste Management

[Member States: Alaska, Hawaii, Idaho, Montana, Oregon, Utah, and Washington (Host)]

The LLW disposal facility in Richland, WA, which was operating when the LLRWPAA was passed, will remain open as the host facility for the Northwest Compact. Also, a contract between the Northwest Compact and the Rocky Mountain Compact (see next section) will result in the Richland, WA facility hosting disposal of LLW from the Rocky Mountain Compact States until their new disposal facility is operating.

In addition, the Northwest Compact has granted authority to the Envirocare Facility in Utah to dispose of non-reactor mixed LLW and large volume, non-reactor bulk LLW from a single site of the following types; slightly contaminated soils, process sludges, demolition rubble, and decontamination and decommissioning wastes.

3.1.3.2 Rocky Mountain Low-Level Radioactive Waste Compact

[Member States: Colorado (Host), Nevada (Host until Jan. 1, '93), New Mexico, Wyoming]

The LLW disposal facility in Beatty, NV, which was operating when the LLRWPAA was passed, remained open and was the host facility for the Rocky Mountain Compact until January 1, 1993. The Beatty LLW disposal facility is no longer accepting LLW for disposal, and is in the process of being closed. Colorado is the host State for a new LLW disposal facility in the Rocky Mountain Compact.

In the meantime, LLW generated in the Rocky Mountain Compact will be disposed at the Richland, WA LLW disposal facility under a contract signed between the Rocky Mountain and Northwest Compacts. The contract, finalized late in 1992, allows up to 6000 ft^3 of Rocky Mountain Compact LLW to be disposed annually at the Richland disposal site, plus a three percent annual increase. Also, there is a special provision for disposal of a total of 140,000 ft^3 of LLW associated with the decommissioning of the Fort St. Vrain nuclear power plant.

Colorado has only recently initiated activities to develop a new LLW disposal facility for the Rocky Mountain Compact. Therefore, there is no a schedule of milestones that shows when the facility is planned to be opened for operations.

3.1.3.3 Southeast Interstate Low-Level Radioactive Waste Management Compact

[Member States: Alabama, Florida, Georgia, Mississippi, North Carolina (Future Host), South Carolina (Host), Tennessee, Virginia]

The LLW disposal facility in Barnwell, SC, which was operating when the LLRWPAA was passed, remains open and is the host facility for the Southeast Compact until January 1, 1996. Legislation signed into law in 1992 allows the facility to accept LLW generated out of the Compact until July 1, 1994, provided that the Host State for the Compact where the waste is coming from or the unaffiliated State that the waste is generated in is making progress in development of a new LLW disposal facility. After July 1, 1994, the Barnwell facility will be closed to LLW generated outside of the Southeast Compact.

Southeast Compact LLW will be accepted at Barnwell through January 1, 1996 provided that conditions concerned with continued progress in North Carolina on development of a new LLW disposal facility for the Southeast Compact are met. Progress on siting and development of a new disposal facility continues in North Carolina. The current schedule indicates that site selection will be completed in October 1993, with facility operations beginning in early 1996, shortly after the Barnwell facility closes.

3.1.4 Compact Regions Without Operating Disposal Sites

Six Compacts without operating LLW disposal facilities, comprised of 23 States, are in various stages of developing new facilities to dispose of LLW generated by their member States.

3.1.4.1 Appalachian States Low-Level Radioactive Waste Compact

[Member States: Delaware, Maryland, Pennsylvania (Host), and West Virginia]

Pennsylvania, the host State for the Appalachian States Compact, is making progress towards development of a new LLW disposal facility. Chem-Nuclear Systems, Inc, the developer of the facility in PA, submitted recommendations for three suitable sites to the Pennsylvania Environmental Quality Board in August 1992 for the Board to determine the next steps in development of the facility. In the meantime, the State of Pennsylvania is in the midst of interactions with the NRC for obtaining limited Agreement State status for the State to obtain regulatory authority over the LLW disposal facility.

The current schedule calls for Chem-Nuclear to submit a complete license application to the Pennsylvania Department of Environmental Resources by early 1994, and for the facility to be operational by mid-1996.

3.1.4.2 Central Interstate Low-Level Radioactive Waste Compact

[Member States: Arkansas, Kansas, Louisiana, Nebraska (Host), and Oklahoma]

A license application was filed with the Nebraska Department of Environmental Control (DEC) by USEcology in July 1990 to construct and operate a new LLW disposal facility just outside Butte, NE. The license was denied by DEC following the review of the application and additional information submitted by USEcology in response to DEC questions raised by the presence of wetlands near the proposed site. The schedule for the original facility called for the facility to be operational by November 1995, but this latest development has changed the schedule. No new projections are available.

3.1.4.3 Central Midwest Interstate Low-Level Radioactive Waste Compact

[Member States: Kentucky, Illinois (Host)]

In October 1992, the Illinois Siting Commission found the proposed site for a new disposal facility in Martinsville, IL unsuitable. The site had been characterized and included in a complete license application submitted for review in May 1991 by Chem-Nuclear Inc. to the Illinois Department of Nuclear Safety (IDNS).

The original schedule for development of the Illinois disposal facility established operations for mid-1994. This schedule has been impacted by the Siting Commission decision and at this time, no new schedule has been established.

The IDNS conducted a survey to determine whether generators would have adequate onsite storage up until the time the disposal facility is operational. The survey indicated adequate onsite storage would be available for approximately two years, so the State has decided not to develop a central interim storage facility.

3.1.4.4 Midwest Interstate Low-Level Radioactive Waste Management Compact

[Member States: Indiana, Iowa, Minnesota, Missouri, Ohio (Host), Wisconsin]

From 1987 until July 1991, Michigan was a member of the Midwest Compact and was the designated Host State for a new LLW disposal facility. On July 24, 1991, the Midwest Compact Commission revoked the State of Michigan's membership in the compact. This action ended Michigan's role as the Host State for the compact, and Ohio automatically became the Host State.

It is estimated that the change in host State will delay the development of a new LLW disposal facility for the Midwest Compact by at least five years. Based on the most recent schedule for development of a new facility in Michigan when it was still the Host State for the Midwest Compact, this delay means that a new facility would be operational in Ohio by 2002 at the earliest. Ohio is in the process of developing enabling legislation and a siting plan to start development of a new facility.

3.1.4.5 Northeast Interstate Low-Level Radioactive Waste Management Compact

[Member States: Connecticut (Host), New Jersey (Host)]

Steady progress was being made in Connecticut toward developing a new LLW disposal facility until Summer 1991. Errors were discovered in Connecticut's site screening process used to recommend sites for further characterization. Several steps were taken to correct the errors and this resulted in a delay estimated at about one year. However, in May 1992, new legislation was signed into law in Connecticut requiring that the entire process for development of a new disposal facility in Connecticut be started over. The previous schedule estimated that site operations would begin in late 1996, but this will no doubt be delayed. No new estimated start of operations date has been set yet.

New Jersey continues with its efforts to progress with site development activities and develop a new LLW disposal facility. Their efforts, however, are lagging behind some other State's progress. Enabling legislation was passed only in June 1991 and the time since then has been devoted to promulgation of regulations and other administrative functions. It is estimated that a new facility will be operational in 1997.

In the meantime, the New Jersey Department of Environmental Protection and Energy formed a task force to address issues and concerns of LLW generators regarding storage of LLW. The task force will look at issues and obstacles generators are facing in preparing for and implementing interim storage of LLW and assisting them in developing solutions to those issues and obstacles.

3.1.4.6 Southwestern Low-Level Radioactive Waste Disposal Compact

[Member States: Arizona, California (Host), North Dakota, South Dakota]

California has progressed steadily towards opening a new LLW disposal facility. USEcology completed site characterization and submitted a license application to the California Department of Health Services (DHS) in December 1989. The DHS completed its review of the license application in 1991.

Currently, the opening of the disposal facility in California is delayed by legal action. The opening of the facility can occur shortly after these issues are resolved, which is estimated to be in the early part of 1993.

3.1.5 Unaffiliated States Planning to Construct Disposal Facilities

There are five States without operating LLW disposal facilities that are in various stages of developing new facilities to dispose of LLW generated in the State. In most cases, these States have chosen not to participate in a compact effort.

3.1.5.1 Maine

Progress on development of a LLW disposal facility continues to be made in Maine. The Maine Low-Level Radioactive Waste Authority's site selection process was working towards reducing the number of candidate sites for further evaluation from five to two at the end of 1992.

Also, Maine has begun to explore other options for disposal of LLW, as Maine is actively pursuing a possible compact arrangement with Texas. Negotiations with Texas are not being conducted by the Authority, therefore, progress on development of a new facility continues on schedule. The current projection estimates that a facility could be operational in Maine by December 1996.

3.1.5.2 Massachusetts

Site selection continues to be on hold in Massachusetts until all LLW management regulations are promulgated. This regulatory effort includes obtaining Agreement State status from the US NRC, which has only recently begun. The current schedule estimates a new facility will be operational in Massachusetts by December 1996.

In the meantime, Massachusetts is developing a program to manage the storage of LLW, perhaps at a central storage location, until a disposal facility is operational, but this effort is also on hold since the Barnwell, SC facility will remain open for acceptance of LLW from Massachusetts until July 1, 1994.

3.1.5.3 New York

Under current NY State law, site selection cannot begin until a preferred disposal method or methods is approved by the LLW facility regulator, the Department of Environmental Conservation. The process of determining the preferred method has just started, and it is estimated that it will take at least two years to complete. Thus, at this time, there is no scheduled date for a new facility to be operating in NY for LLW disposal.

Another effort affecting the disposal facility development process in NY is the recent enactment of legislation in favor of considering the West Valley Nuclear Service Center (WVNSC) site for the location of the NY LLW disposal facility. The legislation resulted from the vote of the Ashford, NY Town Board to reverse the State ban on siting a LLW disposal facility at the WVNSC.

3.1.5.4 Texas

In January 1991, a lawsuit brought by the Counties of El Paso and Hudspeth against the Texas Low-Level Radioactive Waste Authority resulted in the abandonment of siting activities at the preferred site for a new LLW disposal facility at Fort Hancock, TX.

However, following resolution of the appeal process concerning this lawsuit, the Texas legislature gave the Authority eminent domain and limited the location for the LLW disposal site to a specific 400 square mile area outside the Fort Hancock Site. The Authority identified two potential suitable sites on a 16,000 acre parcel of land owned by a private corporation willing to sell the land. Since the new siting region is within 30 miles of the abandoned Fort Hancock site, a significant amount of the characterization work already conducted was applicable to the new siting regions.

Before the Fort Hancock Site was abandoned, a substantial part of the license application had been completed. The Authority revised the license application to include all available information on the new Faskin Ranch site, and submitted the completed sections to the Texas Water Commission for review.

The current schedule in Texas estimates that the complete license review will be completed by April 1994 and operations could begin by January 1996.

The Texas legislature also gave the State permission to enter into a compact with one or more States as long as compact members are limited to a cumulative amount of waste not to exceed 20% of the projected Texas waste generation over a 50-year time period. The Texas governor's office has been contacted by Maine, Vermont, Massachusetts, Connecticut, New Jersey, New Hampshire, Washington DC, Nebraska, and Michigan regarding a compact with Texas, but no formal agreements have been reached.

3.1.5.5 Vermont

Progress on development of a new LLW disposal facility in Vermont has been slow. Vermont law requires that a site at the Vermont Yankee nuclear power station be characterized for possible use by the new disposal site.

However, in September 1991, the Vermont Low-Level Radioactive Waste Authority terminated further characterization work at Vermont Yankee for a number of technical reasons.

In 1992, a program was adopted to provide funding to towns to study the economic and social impacts of hosting the LLW disposal facility. A study was also commissioned to evaluate possible facility designs given the geology and climate of Vermont. The best estimate at this time shows a new facility for disposal of LLW in Vermont opening no earlier than late 1999.

The outlook for a possible compact arrangement with Texas looks better, however. Serious discussions between Texas, Vermont, and Maine have resulted in the drafting of compact language which should be introduced into the Texas legislature this year. If the Texas legislature passes the compact law quickly enough, enabling legislation could be introduced in the current legislative sessions of Maine and Vermont.

3.1.6 Unaffiliated States/Jurisdictions Not Planning to Construct Disposal Facilities

There are five States/Jurisdictions without operating LLW disposal facilities that are not planning to develop new facilities to dispose of LLW generated inside their borders.

3.1.6.1 District of Columbia

The District of Columbia (DC) had a contract with the Rocky Mountain Compact for disposal of their waste through 1992. As of January 1, 1993, when the contract expired, DC LLW could not be accepted at either of the two operating disposal facilities. There is no progress to date on negotiating a new contract or a compacting arrangement for disposal of DC LLW, although the District has had discussions with Texas about the possibility of forming a compact.

3.1.6.2 Michigan

Michigan was the designated Host State for development of a new LLW disposal facility for the Midwest Compact until being expelled from the Compact by the Midwest Compact Commission in July 1991. A primary reason for the expulsion was that restrictive siting criteria established in Michigan made it impossible to find a suitable site for facility characterization. Also, Michigan has long contended that the LLRWPAA is flawed and the mandates of the law are unconstitutional.

Since settling a lawsuit related to their expulsion from the Compact, the Michigan Low-Level Radioactive Waste Authority has been assisting Michigan generators in establishing adequate storage for their LLW. The Authority

is also evaluating whether a central storage facility is required to consolidate storage of LLW. No activities are being conducted in Michigan towards development of a new LLW disposal facility.

3.1.6.3 New Hampshire

New Hampshire also had a contract with the Rocky Mountain Compact for disposal of their waste through 1992. This contract has also expired, and a new one is not in place. New Hampshire has had negotiations with Texas regarding the possibility of establishing a compact, but no formal arrangements have been made. There are no activities being conducted in New Hampshire towards development of a LLW disposal facility.

3.1.6.4 Puerto Rico

Puerto Rico is considered a State under the LLRWPAA, and is required to meet the milestones of the Act. Puerto Rico generates a very small amount of LLW, primarily medical and research waste. Puerto Rico has been out-of-compliance with the requirements of the LLRWPAA since 1986 and has been denied access to any operating LLW disposal facility since 1987. No discussions to arrange for disposal of Puerto Rico LLW are underway or anticipated.

3.1.6.5 Rhode Island

Rhode Island's situation is similar to DC and New Hampshire in that the contract under which LLW generated in Rhode Island was disposed expired on January 1, 1993, and no other arrangements are in place at this time. Unlike DC and New Hampshire, however, Rhode Island has not approached Texas about forming a compact.

3.1.7 Summary

The LLRWPAA contains a target date of January 1, 1996 for States to manage the LLW generated within their borders, and to have an operating LLW disposal facility (although the recent US Supreme Court decision striking down the provision giving title to the States over the LLW takes some of the effectiveness out of this milestone). As can be determined by the previous discussions, the States have made varied progress towards achieving this goal; however, only the Hanford, WA LLW site is assured of being operational on this date. Figure 3-2 shows the projected operational dates (where available) of new LLW disposal facilities being developed under the LLRWPAA.

Project Date of Operation

Host State (Compact)	Status / Projected Date
California (Southwestern)	line ending ~1994
Connecticut (Northeast)	Undetermined
Illinois (Central Midwest)	Undetermined
Ohio (Midwest)	Undetermined
Nebraska (Central)	line ending ~1996
New Jersey (Northeast)	line ending ~1998
Pennsylvania (Appalachian)	line ending ~1997
South Carolina	Operating (until 1996)
North Carolina (Southeast)	line ending ~1997
Washington (Northwest & Rocky Mountain)	Operating
Maine	NA*
Massachusetts	Undetermined
New York	Undetermined
Texas	line ending ~1997
Vermont	NA*

* Texas, Vermont, and Maine will combine.

Figure 3-2. Projected Date of Operation for New LLW Disposal Facilities

3.2 Current and Projected Costs of Commercial Low-Level Waste Disposal

3.2.1 Introduction/Background

As States began to develop new LLW disposal facilities following the passage of The Low-Level Radioactive Waste Policy Act of 1980, it became clear that many aspects of LLW disposal would be different from the practices of the past. One of the biggest differences in LLW disposal will be the costs of disposal, although it is difficult to measure these costs accurately at this point because not enough States or Compacts have progressed far enough with development of the new facilities.

However, many studies have been conducted by the Compacts and States developing new facilities to estimate the costs of developing the facility, and ultimately the cost for disposal of LLW that would be received at the facility. These studies have been conducted over the last 10 or so years, some prior to the passage of the LLRWPAA, and, therefore, they estimate costs of disposal of LLW based on various frames of reference concerning the present situation with commercial LLW disposal. For example, some of the older studies used estimates of volumes of LLW to be accepted for disposal that were higher than what was actually accepted. As such, some of the estimates could be considered "better" than others in reflecting the costs of disposal of LLW. Nevertheless, these studies all present a basis for discussing the future costs of disposal of commercial LLW given the progress of establishment of new facilities discussed in Section 3.1.

One State, California, has progressed far enough that a rate structure was established for operation of the facility, and an estimate of the costs for disposal of LLW if the facility were to begin operations within the next couple of months is available.

3.2.2 Costs for LLW Disposal

The cost for disposal of LLW accepted at a disposal facility is based on the life-cycle costs of developing, operating, and closing the facility, which is divided equitably and charged to generators sending LLW to the facility for disposal. The basic unit of measurement of cost for disposal of waste at operating LLW disposal facilities in the US is $/ft^3 The cost for disposal of a specific package of LLW will be estimated in 1993 dollars. The basic rate will be reported in $/ft^3 multiplied by the volume of the waste package, plus surcharges associated with the weight and surface dose rate of the package and whether additional equipment is required to handle the package, plus taxes, and fees. Disposal costs will also be converted to a cost per m^3 and indicated in parentheses.

The life-cycle costs of a LLW disposal facility include many items that cost money for any construction project of this type, for example, the cost of land acquisition. However, they also include a few costs that are unique to disposal of LLW. The costs include site selection and characterization, licensing, construction, financing, operation, closure, and the return on the investment to the developer and operator and the interest on borrowed capital.

Total life-cycle costs for a LLW disposal facility can be divided into two categories: primary costs and financing costs. Facility costs would vary for private and public developer-operators due to a different tax status, as well as the fact that a publicly financed facility would not include a return on investment. In some of the following discussions, the costs for specific elements would be different for a public versus private LLW disposal facility. Since there are only a few licensed facilities currently operating and each individual cost element is subject to uncertainty, these discussions will not differentiate cost at that level of detail.

Primary costs can be divided further into development costs, operating costs, and postoperating costs. Primary costs are the total cash expenditures expected over the life-cycle of the facility.

Development costs include capital costs and indirect costs for siting, licensing, and construction of the facility. Capital costs include land acquisition, engineering design, buildings, construction management, roads and site preparation, security, environmental monitoring, equipment, legal fees, and facility permitting and licensing. Indirect costs include administrative and general supply expenses incurred during development.

Operating costs are associated with the everyday operation of the facility during the time that it accepts and disposes of waste. These costs include labor, materials, equipment maintenance and replacement, license renewal fees, supplies, environmental monitoring expenses, regulatory expenses, overhead, insurance, financial assurance costs, and annual contributions to a post-operation care fund. This would also include interest on any borrowed funds for a private developer.

Postoperating costs are costs associated with the closure of the site and its maintenance during any institutional control period. These costs are incurred after the facility is no longer accepting and disposing of LLW. Closure costs include building removal and surface work, including backfilling and stabilization and final land contouring. Institutional control period expenses include environmental monitoring and facility surveillance. As mentioned above, a post-operation care fund is established to cover closure and institutional care costs and is collected during the operations period as part of the fee for disposal of waste. Contributions to this fund are made annually and would be invested by the facility. Also, a financial assurance mechanism is required to be in place from the first day of operations of the facility to cover postoperational costs in the event the facility closes earlier than scheduled and not enough money has been collected from LLW generators. The cost of the financial assurance mechanism

is calculated as 2% of the difference between the total required post-operation costs and the amount contained in the post-operations sinking fund. The fee for the financial assurance mechanism is assessed annually.

Financing costs for a private sector LLW disposal facility is equal to the sum of the after-tax cash flows less the total investment made by the developer. For a public sector facility, it is assumed that 100% debt financing was required to build the facility and the financing cost is the interest paid on this debt.

3.2.3 Factors Affecting Costs of Disposal in Future LLW Disposal Facilities

A number of factors influence the elements of cost for disposal of LLW discussed in the previous section. These factors include the size of the site, the amount of waste received, the engineering requirements of the facility, the duration of postoperational care, etc. These factors have influenced the current costs for disposal of LLW, however, it appears that many of the elements contributing to the life-cycle costs for disposal of LLW will be much more expensive for the new LLW disposal facilities being developed under the LLRWPAA. The following factors seem to be the major contributors to estimates that disposal of LLW in the future will be much more expensive than the present.

3.2.3.1 Higher Development Costs

As progress is made by the States and Compacts to establish new LLW disposal facilities, an ever increasing amount of money is being spent on their development. There are several reasons behind these high development costs, including added site selection and characterization steps, increased regulatory requirements, and public and community awareness and involvement.

Siting of the new LLW disposal facilities has become more complicated in most States and has utilized more resources and money. In some cases, notably Texas, Nebraska, and Illinois to date, the original sites chosen to host the facility are not going to be developed further after the expenditure of considerable funds and will no longer host the new disposal facilities. In Texas an alternative site has been chosen after a second site selection and characterization process.

Expensive and thorough characterization of the sites and surrounding communities is being conducted to ensure that environmental effects are held to a minimum and to ensure that baselines for environmental monitoring of the facilities are established correctly. For example, at the new LLW disposal site in California, the protection of the desert tortoise, whose natural habitat could be affected by the facility, has resulted in the expenditure of a great deal of money to study the tortoise's habitat and to develop plans to mitigate the possible effects to the habitat. More money will be spent as the facility moves into operations in order to implement the mitigation plan.

Regulatory and permitting requirements are also causing the expenditure of greater amounts of money. Additional regulatory requirements, beyond Federal and State requirements already in place, have been placed on the facilities by the enabling legislation passed by States to establish the facility under the LLRWPAA. For example, in both Pennsylvania and Massachusetts, the enabling legislation authorizing the development of the new LLW disposal facility required the Host State to obtain Agreement State status with the US Nuclear Regulatory Commission so that the State could regulate the disposal of LLW. This regulatory process is time-consuming and expensive.

Community and public involvement has resulted in additional expense to develop new LLW disposal facilities. Developers/operators have designed and implemented expensive community awareness and outreach programs in an attempt to gain public acceptance of the new facilities before opposition could mobilize against them. Lawsuits have been brought against every new facility as it approached operations, causing added expense.

These factors, and more, have resulted in much larger costs for development than most experts would have predicted. To provide some measure of the spiraling costs of disposal facility development, a 1988 estimate of the cost to develop the new facility in California was $6 million (Gershey, 1990). As of February 1993, the developer/operator had spent $37 million on facility development (Gershey, 1993).

3.2.3.2 Expensive Disposal Technologies

In order to gain public acceptance of new facilities for LLW disposal, States and Compacts found that they needed to consider and decide on the use of highly engineered alternative disposal technologies which were more complex than the technology of shallow land burial employed by past and currently operating LLW disposal facilities. Table 3-1 shows the current Host States developing new LLW disposal facilities and the disposal technology planned to be used or technologies being evaluated for possible use for the new facility in the State. Only California is planning to use shallow land burial. Even there, however, the technology will be enhanced near-surface disposal similar to what is conducted at Barnwell and Hanford, but with changes to the operations to provide greater protection for higher class and higher activity LLW.

The use of more sophisticated engineering technology at these facilities means that many of the life-cycle cost elements will be much higher for new facilities compared to traditional facilities. Costs for facility design will be higher because of more complex systems for items such as environmental monitoring and other facility functions. Construction costs, especially materials, supplies, and equipment, will be much higher. And licensing and permitting costs will be much higher than those for traditional shallow land disposal because regulators will require more time to review and approve the more complex facility. Table 3-2 provides life-cycle cost estimates for each of the engineered disposal technologies being considered for the new LLW disposal facilities (Stanton, 1986).

Table 3-1. Host States and Planned Technologies for LLW Disposal

Host State (Compact)	Planned Facility Operations	Planned Disposal Technology(ies)
California (Southwestern)	1994	Enhanced Shallow Land Burial
Connecticut (Northeast)	Undetermined	Undetermined
Illinois (Central Midwest)	Undetermined	Above-Grade Earth-Mounded Vault with Concrete Canisters
Ohio (Midwest)	Undetermined	Activities not yet initiated
Nebraska (Central)	Late 1995	Above-Grade Earth-Mounded Vault with Concrete Canisters
New Jersey (Northeast)	Late 1997	Undetermined
Pennsylvania (Appalachian)	Early 1997	Above-Grade Earth-Mounded Vault with Concrete Canisters
South Carolina	Operating (until '96)	Traditional Shallow Land Burial
North Carolina (Southeast)	Early 1996	Above-Grade Earth-Mounded Vault with Concrete Canisters
Washington (Northwest & Rocky Mountain)	Operating	Traditional Shallow Land Burial
Maine	NA*	Above-Ground, Roofed Building within another Building
Massachusetts	Undetermined	Undetermined
New York	Undetermined	Undetermined
Texas	Mid 1996	Below-Ground Vault and Concrete Canisters
Vermont	NA*	Below-Ground Vault, Earth-Mounded Vault, or Earth-Mounded Vault with Concrete Canisters

* As discussed, the Texas-Vermont-Main Compact will shortly become official, which will remove the responsibilities of Maine and Vermont to operate LLW disposal facilities.

Table 3-2. Sensitivity of Costs to Disposal Technology

Disposal Technology	Life-Cycle Costs ($ million)
Shallow Land Disposal	196
Below Ground Vault	294
Modular Concrete Canisters	300
Above Ground Vault	395
Earth Mounded Concrete Bunker	434

(Facility to receive 235,000 ft³ of LLW annually for 30 years)

Table 3-3. Unit Costs of Disposal as a Function of Annual Receiving Rate

Receiving Rate (ft³/year)	(m³/yr.)	Annual Cost ($ million)	Unit Cost ($/ft³)	($/m³)
6,000	170	10.8	1,800	64,000
67,000	1,900	10.8	160	5,700
131,000	3,700	12.0	92	3,300

(Below Ground Vault Technology - Private Developer)

3.2.3.3 Reduced and Varying Waste Volumes

One of the most significant factors affecting the disposal of costs of LLW is the volume expected to be received at the facility. This is because volume is used as the basis for equitably dividing up the life-cycle costs for the facility among those who use its services. There are many fixed costs for developing, operating, and closing a LLW disposal facility, and these costs have little variation, regardless of the amount of waste disposed. The cost estimating studies that have been done by States and Compacts have clearly shown the relationship between volume received and unit cost charged to the generator. For example, Table 3-3 (Stanton, 1986) shows the unit costs of disposal as a function of annual receiving rate for a below ground vault disposal facility for the Northeast Compact. Note the small change in annual operating costs even though the amount of waste received changes dramatically.

3.2.3.4 Surcharges, Fees, and Taxes

As a result of increasing public awareness and opposition to the development of new LLW disposal facilities under the LLRWPAA, Compact Commissions and State LLW Development Authorities have proposed incentives and disincentives to win over Local, State, and County governments, citizen groups, environmentalists, and other groups opposed to development of the new facilities. In most cases, incentives will take the form of large contributions from the operator of the facility into the local tax base, to support such items as improvements to roads, schools, the infrastructure, etc. Disincentives may take the form of large fines and penalties associated with problems and abnormal occurrences at the facility. The funds required to make the payments under either of these systems will come directly from the generators using the facility in the form of surcharges, fees, and taxes.

The historical sites using shallow land burial did not have incentive or disincentive programs to consider when they were being established. However, most of them have had incentives and disincentives added to their fees in the form of taxes and local surcharges added over the years of operation. For instance, at the Barnwell, SC disposal facility, a South Carolina LLW disposal tax of $6/ft^3$ ($200/m^3$) is added to the costs of each package of LLW disposed. This tax provides funds for the South Carolina public education system. Also, a $220 surcharge is currently being added to every cubic foot ($8,000/m^3$) of LLW being accepted at Barnwell from outside the Southeast Compact as an incentive to force further development of new LLW disposal capacity.

The magnitude of some of the incentives and disincentives could dramatically affect the cost of LLW. For example, in Illinois, the current law states that the developer/operator of a LLW disposal facility will pay an annual Community Benefit Fee starting at $2.25 million to be adjusted annually for inflation. Using the amount of LLW generated in the Central Midwest Compact in 1991 (104,000 ft^3 or 3,000 m^3) (DOE, 1992) as an approximation, this Fee will add $20/ft^3$ ($700/m^3$) to the cost of LLW disposal in a facility in Illinois when it begins operation.

3.2.3.5 Increased Liability

In recent years, a number of problems have been discovered with near-surface waste disposal facilities. These problems have occurred at municipal refuse landfills and hazardous waste facilities as well as at LLW disposal facilities. Discoveries of previously unknown disposal sites where "midnight" dumping (unauthorized) occurred, and leaking waste disposal sites are but two of the types of problems discovered with disposal facilities. These and other discoveries have led to enactment of federal remedial action legislation such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund") and similar State laws to pay for cleanup of problem waste disposal facilities and to try to prevent reoccurrences of the problems.

Litigation involving the parties potentially responsible for any environmental damage that could be alleged to occur from the problem waste sites has resulted. The combination of cleanup of old disposal sites and the damages awarded in legal cases results in extremely high costs for parties found responsible for the problem waste sites. Operators of future LLW disposal facilities will need financial mechanisms, including liability insurance, to protect themselves against unforeseen occurrences that could result in problems at the disposal facility. Liability insurance coverage and other financial mechanisms established for this contingency will be very expensive and will add to the total costs of operating a newly developed LLW disposal facility.

3.2.3.6 Disposal of Commercial Mixed LLW

A factor that could affect the costs of disposal of LLW is the possibility that commercial mixed LLW will need to be disposed of in the LLW facility being developed under the LLRWPAA. Although it could be possible to develop another separate facility for mixed LLW disposal, it may not be feasible at this point considering the small volume of mixed LLW and the difficulty establishing a new facility for LLW without hazardous constituents in the waste. A more likely scenario would be for a new LLW disposal facility to propose changes to design and operation to accommodate the small amount of mixed LLW in storage and newly generated mixed LLW that needs disposal. This facility would recover the costs for changes and additions to dispose of mixed LLW by establishing a separate fee for mixed LLW disposal. However, facility modifications and operations changes will naturally affect the costs for LLW disposal, making it more expensive. There also would be the possibility that an operator would recover some of the costs for mixed LLW disposal from LLW generators since the operator may not take the chance that the small amount of mixed LLW to be received can cover the full costs of operations without establishing a charge rate that they feel would be prohibitively high and would not be supportable by the industry. A measure of the difference in LLW versus mixed LLW disposal can be found at the Department of Energy Hanford Central Waste Complex where LLW disposal costs $44/ft^3 ($1,600/m^3) compared to $133/ft^3 ($4,750/m^3) for mixed LLW storage. The difference is quite large even without a charge added to the mixed LLW for its eventual disposal.

3.2.3.7 Facility Lifetime

Another factor that affects the costs of disposal of LLW is the projected lifetime of facility operations. Since the life-cycle costs are the basis for the disposal charge passed onto the generators, the number of years that money will be collected from generators is crucial in determining the unit charge for waste disposal. Most State and Compacts are planning for facilities to have either 20- or 30-year operating lives. The charge would obviously be greater per waste volume unit if a facility was planned to operate for 20 years versus 30 years.

3.2.4 Future LLW Disposal Costs

As previously mentioned, future LLW disposal costs have not been determined yet because most of the States and Compacts have not progressed enough to determine the full life-cycle costs for the new disposal facility being developed, and therefore, the unit charge rate for disposal. Most States and Compacts have commissioned studies to estimate how much it will cost to dispose of LLW in their new disposal facilities. Many of the factors causing increases in cost elements have been recognized and taken into account in these studies. This is especially true of the affects of engineered alternatives and the reductions in volumes to be received for disposal at the new facilities.

These studies have been conducted over the last 10 years or so, and as such, contain assumptions to formulate the estimates that may not be accurate in today's political and economic environment. Nevertheless, these estimates provide some measure of what LLW disposal will cost in the future. Table 3-4 shows the estimated future costs for disposal of LLW contained in selected studies for Compacts and States. The results selected to be included in this table are from some of the more contemporary studies conducted. Other studies that were performed in the early 1980s do not reflect recent developments in the establishment of new LLW disposal facilities and those results are not included in the table. (For comparison purposes, the cost for disposal of LLW in 1988 was approximately $25/ft^3 ($900/m^3), not counting taxes, fees, and other surcharges).

The studies conducted for New York and Texas in 1988 reflect an estimated cost for future LLW disposal of four times the rate being charged by the LLW disposal facilities operating at the time the study was conducted. Using the same relationship, an estimate of future disposal costs would be approximately $160/ft^3 ($5,700/m^3) based on the current charge rate for disposal of LLW of $40/ft^3 ($1,400/m^3), excluding surcharges, taxes, and fees.)

The clearest indication of the costs for LLW disposal in the future comes from the development of the new LLW disposal facility in California. Even though ground has not been broken there, and uncertainty still exists regarding when operations will begin, the design, engineering, licensing, and other preoperational activities have progressed enough for a rate structure to be established for the facility. It is estimated by USEcology that if operations were authorized in February 1993 to begin as soon as possible, the unit cost for disposal at the California facility for

Table 3-4. Selected Cost Estimates for Future LLW Disposal

| | | Estimated Unit Disposal Cost | | |
Study	Year	($/ft^3)	($/m^3)	Comments
Northeast Compact Study (Ref. 9)	1988	$77 - $1800	$2,750 - $64,000	Below Ground Vault design (1800/ft^3 for Class B/C waste facility)
DOE Study (from Ref. 10)	1985	$23 $40 $48 $142	$800 $1,400 $1,700 $5,100	Shallow Land Burial (SLB) Improved SLB Augured Holes Mined Cavities
Rogers Study (from Ref. 10)	1985	$30 - $40	$2,800 - $3,600	SLB, Above and Below Ground Vaults and Concrete Canister designs evaluated
New York Study (from Ref. 6)	1988	$80 - $100	$2,800 - $3,600	Below and Above Ground Vault and Mined Cavity designs evaluated
Texas Study (from Ref. 6)	1988	$80 - $100		Below Ground Vault design

disposal of LLW would be $250 - $300/ft^3 ($9,000 - $11,000/m^3) (Shaffner, 1993). The estimated charge rate also rises dramatically with delay, due principally to continued environmental monitoring and payment on borrowed money. USEcology estimates that with each 1 month delay, the charge rate is rising as much as $25/ft^3 ($900/m^3) (Shaffner, 1993).

A recent development reported in Chapter 1 that provides some optimism concerning the costs for disposal of LLW is the opening of the Envirocare disposal facility in Utah. This disposal facility only accepts large volume, non-reactor bulk LLW from a single site of the following types; slightly contaminated soils, process sludges, demolition rubble, and decontamination and decommissioning wastes. However, accepting only these limited high volume slightly contaminated waste streams allows the Envirocare facility to charge very low rates, on the order of $4/ft^3 ($140/m^3), for disposal of the waste. Recognizing the major differences between this facility's design, operation, regulation, etc. and the new LLW disposal facilities being developed that will be able to accept all LLW streams, it is no surprise that it can charge such a low rate for disposal of waste. However, at least it affords relief for waste generators for some of the waste streams to be generated. This is especially true of decontamination and decommissioning projects, which can dispose of large quantities of low-activity waste such as building rubble and soil at a much reduced rate than at new LLW disposal facilities being developed under the LLRWPAA.

3.3 Summary/Conclusions

Progress on development of new LLW disposal facilities under the LLRWPAA is slow. Only California, the Host State for the Southwestern Compact, is close to operating a new disposal facility, and it is not certain when the final roadblocks to its opening can be removed. Two States that had been making significant progress were recently dealt serious blows, when both the Illinois and Nebraska sites selected to host the new LLW disposal facilities were found unacceptable. Even though the Barnwell SC LLW Disposal Facility is still open to all LLW, some generators are storing the LLW they generate in order to avoid paying the out-of-Compact surcharges. In the future, more generators will need to store LLW they generate, and only a couple of States have organized programs to evaluate the adequacy of generator's storage and to see if the State needs to establish centrally managed LLW storage.

When the new LLW disposal facilities do open, it is certain that costs for LLW disposal will be much higher than in the past. The best measure of the future costs for LLW disposal is California, where a rate structure has been established for disposal of LLW at the new facility. The developer/operator of the California facility, USEcology, estimates that, if the facility were authorized to open today, the charge for LLW disposal would range from $250-$300/ft^3 ($9,000 - $11,000/m^3). While no charge rates are available at this time for other new LLW disposal facilities, it is possible that charge rates will be in the same range as California's.

The Envirocare disposal facility in Utah will provide some relief on the costs for disposal for some LLW generators, as the facility has been approved to accept large volume, non-reactor bulk LLW from a single site of the following types; slightly contaminated soils, process sludges, demolition rubble, and decontamination and decommissioning wastes. The current charge rate for disposal of large volumes of these waste streams at Envirocare is approximately $4/ft^3 ($140/m^3).

4. DECONTAMINATION TECHNOLOGIES

Various techniques and processes have been developed, demonstrated, and effectively used for the decontamination of radioactive materials from nuclear facilities. This chapter provides an overview of many of these technologies, focusing on those technologies which may be used prior to the recycle or reuse of metallic materials. Table 4-1 summarizes the major characteristics of various decontamination technologies. For each technology, the table provides a general description, the materials or chemicals used for the process, typical decontamination factors (DFs), wastes produced by the process which ultimately require disposal, an example application of the process, any quantitative or qualitative cost data that was available, reference documents, and miscellaneous comments.

Decontamination processes can be classified as either surface decontamination processes or volume decontamination processes. Surface decontamination processes are generally either an abrasive or high pressure cleaning process or a chemical bath process. Volume decontamination processes are necessarily destructive in nature and generally involve either the melting of metal with thermal or electrical energy or the electrical dissolution of the metal, in order to release or redistribute radionuclides bound in the metal matrix. The decontamination technologies summarized in Table 4-1 are grouped by surface decontamination technologies and volume decontamination technologies. The process identified in the literature as "CONAP" involves both a surface chemical decontamination and a volumetric decontamination by melting in a foundry.

The materials and chemicals identified on Table 4-1 include abrasives, solvents, detergents, etc. used in blasting and cleaning processes; various acids and complexing agents used in chemical and electrochemical processes; and fluxes used in foundry and melting processes. In general, the materials and chemicals required are standard industrial commodities that are readily obtainable.

The decontamination factor (DF) is defined as the ratio of activity before and after the decontamination process. Total activity measured can be divided by either the mass or the surface area of the item being surveyed, giving units such as Bq/g or Bq/cm^2. Surface area based DFs are used for surface decontamination processes. Volume based DFs are used for volumetric decontamination processes. The referenced literature occasionally gave numerical DFs for specific processes; if so, these are included in the table. Somewhat less frequently, the literature stated only that either "low" or "high" DFs were typical, with a value of roughly 10 being a dividing line. For many processes, no data concerning DFs could be readily found. DFs quoted in the references range from less than unity for one process under development (obviously not beneficial under the conditions represented by the experimental run which yielded this value) to 10,000 or more for a particular electropolishing process and for a process that combined chemical surface decontamination and melting in a foundry.

Table 4-1. Summary of Decontamination Technologies

Decontamination Technology	General Description	Materials/ Chemicals Used	Typical DF(s)	Waste Produced Requiring Disposal	Example of Application	Cost Data	Reference	Comments
- SURFACE DECONTAMINATION TECHNOLOGIES								
Vacuum cleaning	Vacuuming used to remove loose contaminants such as dust of particulates from a surface or to collect dust from other processes.			Collected contamination.		Inexpensive	Feraday 1989; Koch 1991	Most widely and frequently used meth to remove loose contamination.
Brushing, washing, or scrubbing	Manual or power brushing to remove loose or soluble contamination.	Solvents, detergents, or soluble abrasives may be added to improve performance.	"High" DFs possible	Liquid waste stream and dislodged solid wastes; filters, precoat, and resin.		Labor intensive, but relatively inexpensive	Feraday 1989; Koch 1991; NDC 1992	Potential for higher occupational exposur although remote operation is possible i some cases.
Water-based processes:								
Liquid Abrasive Blasting/Decontamination (LAB/ LAD)	Abrasive action of solid grits or particles entrained in high volume water stream at 100 psi removes corrosion products from contaminated metal. Air injection can improve effectiveness.	Aluminum oxide particles, glass beads, sand, or metal particles.		Solidified grits (water can be recycled - if it is, spent resins would presumably need to be disposed of).			Koch 1991; Whitfield 1991	Effective in removing Alpha contamination. Once-through process not adequate for removing Beta contamination since it ca be hidden in cracks, folds, edges, etc.
High pressure water / steam jetting	Water or steam jets are directed at high pressures (3000-6000 psi) onto contaminated objects to remove loose or fixed contamination, as in paint or rust.	Solvents, detergents, or soluble abrasives may be added to improve performance.		Liquid waste stream and dislodged solid wastes.	Tests conducted at Oak Ridge K-26 Site.	Unit costs ($/ton): Average - 700 Ferrous scraps - 500 Aluminum scraps -1500	Feraday 1989; Koch 1991; Whitfield 1991	A spray process may used for vertical surfaces, while a spir process may be used horizontal surfaces.
Ultra high pressure water decontamination	Water at pressures up to 35,000 psi blasted onto surfaces with nozzles about 1 inch from the surface removes heavy oxidation/surface coatings. Fine abrasives can enhance performance.	Garnet, aluminum oxide, or iron fillings, with grit size 40 to 120 mesh.		Liquid waste stream; spent ion-exchange resins, if contaminated water is recycled; grits, if used.			Whitfield 1991	
Flowing abrasive	Grains of abrasives are suspended in water and circulated through a system. The grains hit or rub the inner surfaces of pipes and components, removing CRUD mechanically	B_4C particles	1100	Abrasives, sludge, cartridge filter	Decontamination of a portion of the Japan Power Demonstration Reactor (JPDR) primary coolant system		Yasunaka et al.	
Freon cleaning	Freon solvent directed onto the surface under high pressure.	Freon		Filter cartridges and some mixed waste.			Feraday 1989; NDC 1992; Whitfield 1991	Non-destructive; effective on tools, electric motors, precis parts, delicate compo nents, etc.

Table 4-1. Summary of Decontamination Technologies (continued)

Decontamination Technology	General Description	Materials/ Chemicals Used	Typical DF(s)	Waste Produced Requiring Disposal	Example of Application	Cost Data	Reference	Comments
Dry grit blasting	Hard abrasive materials are directed with compressed air at high velocities.	Sand, carborundum, or metal particles; compressed air.		Grits, filters, precoat.	100,000 lbs. of slightly radioactive steel scraps were decontaminated for unrestricted release at the Argonne Nat'l. Labs in 1991.		NDC 1992; Whitfield 1991	Argonne decontamina scrap was sold for $92/ton. Process sav an additional $150K (waste packaging and disposal.
Ultrasonic cleaning	High frequency mechanical vibrations are induced in a bath of solvent, resulting in cavitation on the surfaces of the objects, which abrades the surface contaminants. Addition of chemical reagents can intensify the process.			Liquid waste stream, depending on solvent bath; dislodged solid wastes.			Feraday 1989; Koch 1991; Whitfield 1991	Effective for small reusable equipment, metal tools, valve par filter elements, precisi equipment.
Ice-blasting	Mechanical process using 2-5 mm ice particles fed into compressed air stream; removes soft crud to reduce radiation exposure during maintenance and inspection work.	Solid H₂O, compressed air	2	No secondary solid waste; "less" secondary liquid waste then conventional mechanical methods (hy-drojet cleaning, manual brush cleaning)	Used in Japan to decontaminate pump casings, valves, and primary circuit piping of BWRs.		Oguchi 1989	Literature doesn't specifically cite uses (pre-recycle decontami tion; described as a means of removing sc crud prior to visual/dy penetrant examinatior of base material.
High concentration chemical decon-tamination processes	In general, refers to processes with reagent solutions of higher than 1% (2-15%). Some special processes appear as separate table entries below.	Nitric, HCl, sulfuric, citric, oxalic, or HF acids; EDTA; complexing agents; inhibitors	>10	Liquid wastes; solid wastes, including filters, precoat, and resin; mixed wastes, if acid is used; and secondary waste.			Feraday 1989; Koch 1991; NDC 1992; Whitfield 1991	Can be destructive. Some named high-cor processes are NOPAC CITROX, TURCO 462 NS-1
Low concentration chemical decon-tamination processes	In general, refers to processes using reagent solutions of 1% or less. Re-agents can be added directly to the coolant of an entire reactor coolant circuit. Some special processes appear as separate table entries below.	Oxalic acid, formiate, picolinic acid, citric acid, EDTA	14-86	Same as above, in general. Chemicals can be regenerated.	Decontamination of the primary coolant system of the reactor BR3 in Mol, Belgium using the "CORD" process.		Feraday 1989; Koch 1991; Whitfield 1991	Have been used for o 20 years. Non-destructive and more suitable for decon-taminating items whic are intended for furthe use, such as entire re tor coolant circuits or single components. Some named low-con processes are CORD, LOMI, CAN-DECON, CANDEREM, POD, an MOPAC 88.
Pre-oxidation/ reducing decontamination process	Complex chemical immersion methods utilizing a chemical bath. The process treats the object by two steps: pre-oxidation and reduction. The liquid waste stream can be treated using a reverse osmosis (RO) process.	KMnO₄, HNO₃, oxalic acid, NS-1	520	Condensed waste solution (15% of system volume), RO module	Decontamination of a portion of the Japan Power Demonstra-tion Reactor (JPDR) primary coolant system		Yasunaka et al.	

Table 4-1. Summary of Decontamination Technologies (continued)

Decontamination Technology	General Description	Materials/ Chemicals Used	Typical DF(s)	Waste Produced Requiring Disposal	Example of Application	Cost Data	Reference	Comments
Redox decontamination	Sulfuric acid and cerium (IV) used in a two-step process: decontamination and liquid waste treatment.	H_2SO_4, cerium (IV) sulfate, cerium (IV)	900	Condensed waste solution, regenerated sulfuric acid, ion exchange membranes, cartridge filters, resin	Decontamination of a portion of the Japan Power Demonstration Reactor (JPDR) primary coolant system.		Yasunaka et al.	
Regenerative Nitric/HF Process	Material is soaked in a dilute solution of nitric and hydrofluoric acids. Solution is regenerated using a strong acid cation exchanger.	Dilute solution of nitric (0.5 to 1.0 wt%) and hydrofluoric (0.06 wt%) acids	10	"Small volume" of spent ion exchange resin and recovered acids in concentrated form.	Decontamination of irradiated fuel storage baskets (304 S.S.) from Pickering Nuc. Gen. Station.		Husain 1988	
Electro-chemical decontamination (a.k.a., electro-polishing)	The process is the reverse of electroplating. Anodic dissolution removes contamination on or in metal surfaces by the controlled removal of a thin layer of surface metal including corrosion films.	Phosphoric, sulfuric, or oxalic acid as an electrolyte.	Decon. to background level is feasible	Volumes of secondary waste solutions are low, but they may require special chemical treatment before disposal.	Successfully applied to metal scrap from the steam, condensate, and feed-water cycle during decommissioning of Grundrem-mingen A.	Expensive process: employed as a last resort or for high value metals. Labor intensive.	Feraday 1989; Koch 1991; Whitfield 1991	May be applied to surface contaminatic but generally employ for volume decontan tion. Personnel expc can be a problem.
CO_2 grit blasting	Solid CO_2 particles are propelled by compressed air onto the surface to be decontaminated. CO_2 particle shatters on impact and flashes into dry CO_2 gas. Foreign materials are captured on HEPA filters.	Solid CO_2 (dry ice)		Used HEPA filters	Decontamination of materials from Surry, N. Anna, Fitzpatrick, Oco-nee, Clinton, Beaver Valley, Pilgrim, Millstone 2, and NNP 1.		NDC 1992; Whitfield 1991	
Advanced decon-tamination systems	Some techniques currently in various stages of R&D are laser decontamination, microwave decontamination and accelerator transmutation of wastes.						Whitfield 1991	These may also be explored as potential ume decontaminatior technologies.

- VOLUME DECONTAMINATION TECHNOLOGIES

Melt-refining	Metallic scrap is melted in an induction or other furnace; slag and filter dusts are separated, and the re-covered metal can be reused for the construction of shielding plates and casks for the transport of radioactive material. State-of-the-art experience in a specific technique known as zone refining or polishing has been gained by the nickel processing industry.	Borosilicate glass flux.	Steel: <2 Copper: 50 Brass: 20-100	Slag (2-5 vol%) and filter dust (0.1 vol%). Other secondary waste components are furnace lining and used filters.	(Planned) melting of some 1700 t of metal scrap from the de-commissioning of the Nelde-rachbach plant.	Unit costs ($/ton): Ferrous scrap - 800 Aluminum scraps - 2400 Copper scraps - 1500	Sappok 1991; Sappok 1989; Schuster 1989; Seidler 1987; Whitfield 1991	Literature focuses or melting for column reduction, reusable products for the nucl sector. Experimental melting of scrap stee shows that 80-90% radioactivity remains melt (mainly Co60). Aerosols are released during the melting pr-cess.
Electro-refining	Electro-kinetic separation of metals and radionuclides. May be performed in the aqueous/liquid phase or in the molten metal phase.	Chemical usage is minimal.		Waste generation is minimal.		Suitable for areas where electricity is inexpensive.	Whitfield 1991	

Table 4-1. Summary of Decontamination Technologies (continued)

Decontamination Technology	General Description	Materials/ Chemicals Used	Typical DF(s)	Waste Produced Requiring Disposal	Example of Application	Cost Data	Reference	Comments
Electroslag refining (ESR)	Contaminated metallic waste in the form of a rod, cylinder, or tube becomes an electrode which is inserted into a water-cooled copper furnace mold. Electrical power is supplied and joule heat melts the electrode, forming an ingot.	Fluxes consisting of 40 SiO2,-30 CaO-20 Al2O3- 10 CaF2 for iron and 14 LiF-76 HCl-10 BaCl2 for aluminum	<1 to 10	Slag, filter dust.	Experimental	More energy-efficient than resistance furnaces.	Uda 1987	
- NAMED PROCESSES INVOLVING A COMBINATION OF SURFACE AND VOLUME DECONTAMINATION								
CONAP	Alkaline pre-treatment, oxidation phase with potassium permanganate in an acidic media, dissolution phase using a complexing agent, and rinsing phase, followed by melting of material in foundry.	"Alkaline" (?), potassium permanganate, "acidic media," complexing agent.	>10,000	Radioactive sludge, filter dust, slag.	8 t of stainless steel piping from Tihange I recycled; yielded 145 l of sludge and 163 kg of filter dust and slag.		Hebrant 1989	Process carried out in less than 3 weeks; volume of chemical s tions used was only : m³; reusable producti shielding blocks weig 28 kg; literature was specific as to chemic used.

When considering DFs, it is important to understand that the DF for a process may be very specific to the type and composition of the contamination being removed. Processes which are not well suited to the type of contamination to be removed may be simply ineffective, or they may make existing contamination more difficult or even impossible to remove. For example, when melt-refining scrap steel, it has been demonstrated that most of cobalt, silver, and other radionuclides remain in the melt and the final ingot. If scrap steel that has surface contamination containing Co-60 is intended to be recycled, it would be a serious mistake to attempt melt-refining without first applying an effective surface decontamination technique. Otherwise, the Co-60 which was initially only on the surface would become evenly distributed through the metal. Similarly, uranium tends to adhere to aluminum during melting. However, in this case, special fluxes can be used to remove the uranium from the aluminum. In contrast to cobalt, americium is almost completely transferred to the slag in the melt-refining of steel. Cesium is largely volatilized or adsorbed by the slag. Tritium present as surface and volume contamination in components of heavy water cooled/moderated reactors is removed by volatilization. Technetium-99 is difficult to remove by melt-refining in most metals except aluminum.

Table 4-1 identifies for each process listed, the waste products generated which ultimately need to be disposed of. These waste products include both primary and secondary wastes. Primary wastes are the solid, liquid, or mixed wastes resulting directly from the contamination or the process commodity directly applied to remove it. Secondary wastes are generally the materials or items which become contaminated or which hold contamination as a result of the process or as a result of secondary processes, such as ion exchange treatment of recyclable process water. Secondary wastes include things such as filter elements and dust, spent ion exchange resins, slag, and furnace linings. For more detailed cost/benefit analyses which may be performed in the future, the cost liabilities for disposing of these wastes would need to be factored in on the debit side of the cost/benefit equation.

Limited data was available on the quantity of wastes produced by various decontamination processes. This was due mainly to the fact that there have been few large-scale applications of decontamination technologies. Most of the reference documents were written to publish the results of small or laboratory-scale application of various processes when they were used for specific decontamination projects. When this was the case, the specific project is mentioned in Table 4-1 under the column entitled "Example of Application." These projects have been carried out in the U.S., Canada, Europe, and Japan.

Cost data obtained to date is somewhat sketchy, but is included in Table 4-1 where available. Some quantitative cost data is included, but for the most part, the data provided is qualitative in nature, e.g., the relative expense of one process versus another, or the fact that a process is relatively inexpensive, or so expensive as to be prohibitive except under certain circumstances.

5. RECYCLE OF METAL IN THE UNITED STATES AND WORLDWIDE

5.1 Introduction

This chapter examines the recycle and reuse efforts for contaminated and non-contaminated metals in the US and world-wide.

Section 5.2 summarizes the US commercial recycle industry for iron and steel, copper, and aluminum. A separate subsection for each metal is divided into four parts.

1. The "Overview of Domestic Production and Use" section provides an overall material flow for each metal, a summary of salient statistics, as well as information pertaining to how the metal is processed, major categories of consumers, and distribution of products.

2. The "Scrap Recycling Industry" section describes the scrap recycling industry for each metal, how much scrap is generated, its type and how it is processed. Information related to recycling rates and product lifecycles is presented where available. Estimates of total old scrap generation and consumption by scrap type, or grade, is also provided.

3. The "Factors Relevant to Cost Benefit Studies" section provides relevant information such as: accident statistics (i.e., worker injury/fatality rates), scrap prices and their relationship to scrap supply and demand, studies which have estimated the cost of metal refining versus recycling, energy requirements for various processes, etc.

4. The "Factors Relevant to Worker Exposure Scenarios" section provides information that may be relevant to dose pathway calculations. This section includes information relevant to how byproduct materials (i.e., process slag and fumes) are generated, processed and disposed of, as well as relevant regulatory issues and/or standards for a particular metal.

Section 5.3 examines metal recycle and reuse for nuclear contaminated metals. The primary focus is on US activities in this area with a brief summary of international activities. Specifically, estimates are provided for the total volume of contaminated metal scrap in storage and the annual generation rate for contaminated scrap in the US. Breakdowns of the annual generation of contaminated scrap by metal are also provided, as well as a discussion of the techniques that are currently employed to process contaminated scrap.

5.2 US Commercial Metal Recycle Industries

This section summarizes the commercial metal recycling industry for iron and steel, copper and aluminum. The information is intended to provide a "snapshot" overview of the entire recycling industry for each metal, using 1990

data. Special emphasis is placed on the handling and treatment of old scrap (sometimes referred to as obsolete, or post-consumer scrap), as any metal material coming from decommissioning and decontamination activities in the nuclear industry would be considered to be old scrap.

Any material which has sufficient metal content for recycling is referred to as scrap metal. Although the definitions may vary somewhat by industry, there are three general categories of scrap metal that are used in the various metal fabrication processes, they are: home, new, and old scrap.

- Home scrap (also called revert or runaround scrap) consists of unusable products that are produced during the processing or fabrication of a metal into a form which is usable for manufacturing. Home scrap that is produced during metal fabrication can include items such as cuttings and trimmings from castings, rejected ingots, and damaged or rejected material. The amount of home scrap generated and its use varies by metal industry.

- New scrap (or prompt industrial scrap) is generated by companies during the manufacture of consumer or industrial finished products. It may consist of machine turnings, flashes from forgings, trimmings from pressing and stamping operations, etc. New scrap is generally of high quality and its chemical and physical properties can be well documented. As such, it is generally more expensive than old scrap.

- Old scrap (also called obsolete, dormant, or post consumer scrap) includes obsolete, worn out or broken products which have been consumed by the general public or in industrial applications. Depending on the type of metal and its composition, old scrap may either be directly melted to form a product of specific chemical composition, or it may be refined into pure metal to remove impurities before processing. As such, old scrap normally requires careful sorting and classification.

Although it may vary somewhat among different metal industries, the primary producers are involved in the reduction of mined metal ore into its pure metallic form while the secondary producers are mainly involved in processing scrap. Some "integrated" primary producers have fabrication and manufacturing capabilities at the mine site and are also consumers of scrap. In addition, some metal reduction processes use a certain amount of scrap as feed.

Figure 5-1 provides a generalized diagram showing how different types of scrap are generated and recycled. As shown in the figure, production and consumption of metal create a feedback of scrap to the production cycles. Home scrap is generally reused directly by the fabricator and since it does not leave the process facility, most estimates of scrap utilization do not include home scrap. New scrap does not normally require any preparation for reprocessing and it can be directly reused by the primary and secondary industries. Most new scrap generated in the production of end products is recycled to the production cycle immediately after it is generated. The amount of new scrap which is purchased by brokers before being recycled to the production cycle varies according to the form and end-use of the metal as well as its recycle value. For old scrap, however, virtually all metal which is recycled is purchased by brokers according to the demand. Thus, the recycle time for old scrap is normally much longer than for new and home scrap. Also included in the figure are the scrap dealers that often purchase and
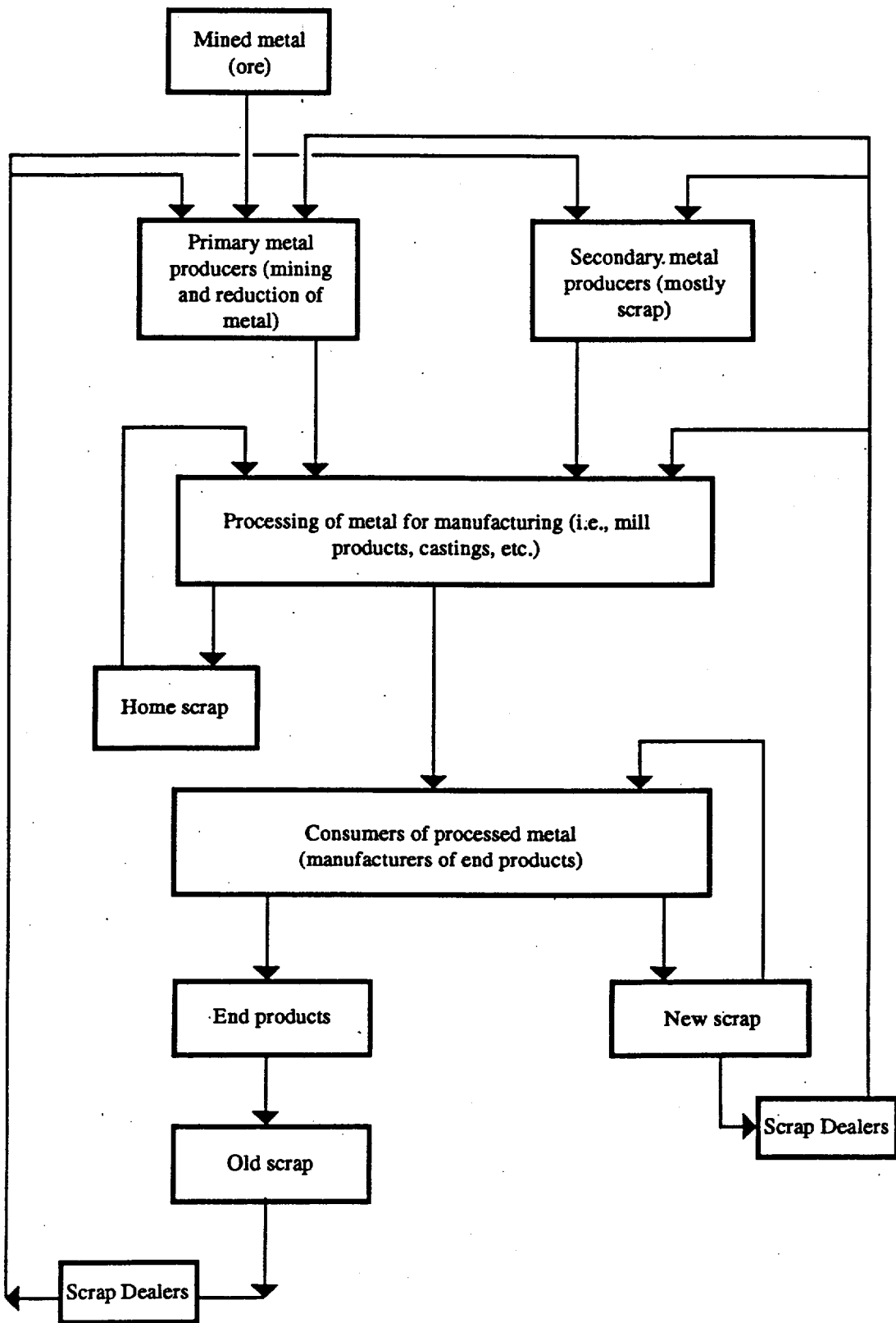
Figure 5-1: Generalized Diagram of Scrap Generation and Recycle Paths in the Production of Metal

collect scrap from industrial sources and commercial collectors and sell it back to fabricators and primary and secondary consumers.

The recycling rate for various metals depends not only on the availability of the scrap, but also on its residual value. Aluminum and copper have very high residual value. As such, the supply of available scrap for those metals generally does not meet the demand. For these high value metals, it is generally economically attractive to process any scrap that may be available and the recycling rate for these metals is often referred to as "supply-driven." Although prices have tended to fluctuate historically, current scrap prices for aluminum and aluminum alloys average about $0.75 per pound, while copper and copper alloys average slightly more than $1.00 per pound. For supply-driven metals, the recycling rates are linked to their availability and the technological ability to recover the metal from the form of scrap. Iron and steel scrap on the other hand, has traditionally had very little residual value (on the order of a few cents per pound) with supply far exceeding demand. Because steel scrap is a "demand-driven" commodity, the ability to recycle a given volume of scrap depends both on the quality of scrap (i.e., its chemical characteristics) and its location (i.e., the cost associated with delivering the scrap to a dealer for recycling).

The following subsections provide a more detailed description of the iron and steel, copper and aluminum commercial recycling industries, respectively.

5.2.1 Iron and Steel Recycling Industries

5.2.1.1 Overview of Domestic Production and Use

Steel is made primarily of iron and carbon with thousands of varieties possible by varying the content of iron, carbon and alloying elements. The carbon content can vary from 0.25% to 2% while harder grades have a higher carbon content. Alloy steels contain certain alloying elements such as chromium, nickel, manganese, silicon, vanadium and molybdenum, which make them more resistant to wear, corrosion and heat than carbon steels. Stainless steel is the most popular of the alloy steels. The most common of the stainless steels contain 18% chromium and 8% nickel.

A number of different furnace operations are employed to reduce iron ore or scrap into the various grades of steel. Iron ore which is mined is processed in a blast furnace to produce hot molten iron, or "pig iron." Pig iron and iron and steel scrap are the sources of iron for steelmaking in basic oxygen and open hearth furnaces; electric furnaces rely almost exclusively on iron and steel scrap.

Facilities involved in iron and steel include ferrous foundries, steel mills, and the ferrous scrap industry. Foundries pour molten cast iron or steel into molds to produce casting with the approximate shapes of final products. Steel mills cast relatively simple steel shapes that the mills roll or hammer into finished products, such as sheet, bar, or structural shapes. Steel mills can be divided into two categories. The first category is integrated mills, which produce pig iron from ore (a small amount of scrap is sometimes added to cool the metal), refine the pig iron into steel, and process it into a form suitable for manufacture, usually flat products like sheet and strip. The entire integrated process is normally located at or near a mine site. The second category of steel mills are the non-integrated mills, which melt scrap in electric arc furnaces and cast the steel in continuous casting machines.

Steel Production Data

The steel industry consists of about 75 companies that produce raw steel from mined ore and scrap at 120 locations, with a combined production capacity of about 107 million MT. The 1990 production of raw steel was about 89.9 million MT, corresponding to 11.6% of world production and 84.7% of the total US combined production capacity. The integrated plants accounted for approximately 63% of total steel production in 1990 (Peters, 1992; AISI, 1990). Figure 5-2 summarizes the iron and steel production material flow for 1990. Note that the data for reported scrap consumption in Figure 5-2 is for all types of scrap (home, new, and old), since the Bureau of Mines data does not differentiate between different types of scrap. Table 5-1 provides a summary of salient statistics for iron and steel.

About 87.5% of all steel production is carbon steel, with alloy steel accounting for about 10.4% and stainless steels about 2.1%. Table 5-2 summarizes the production of raw steel by grade of steel and type of furnace. In terms of type of cast, about 60.6 million MT (67.4%) of steel was produced by continuous casting, with about 29.3 million MT (32.5%) produced in ingots (AISI, 1990).

Mining

According to the US Bureau of Mines, there was about 49.7 million MT of iron ore produced by 20 companies operating 22 mines (21 open pit and one underground), 16 concentration plants, and 10 pelletizing plants in 1990 (Peters, 1992; US Bureau of Mines, 1992). About 98% of iron ore is consumed in blast furnaces to produce crude liquid iron, or "pig iron," with a small amount consumed by foundries and directly reduced into products. In 1990, total consumption of pig iron was about 51.1 million MT.

Integrated Steel Mills

Pig iron was produced by 13 companies operating integrated steel mills, with 46 blast furnaces. Almost all pig iron produced was delivered in liquid form to basic open hearth or basic oxygen furnaces located at the same site for

Primary
"Integrated"
Producers

Scrap[b]

2,570

Ore

Blast Furnaces

Pig Iron

49,431

336   1,374

Direct Casting
of iron

To non-
integrated
producers

Scrap[b]

652

1,236

48,195

Scrap[b]

15,014

Open Hearth
Furnaces

Oxygen Furnaces

Liquid iron and scrap refined
into raw steel and
manufactured into products -
mainly sheet and strip.
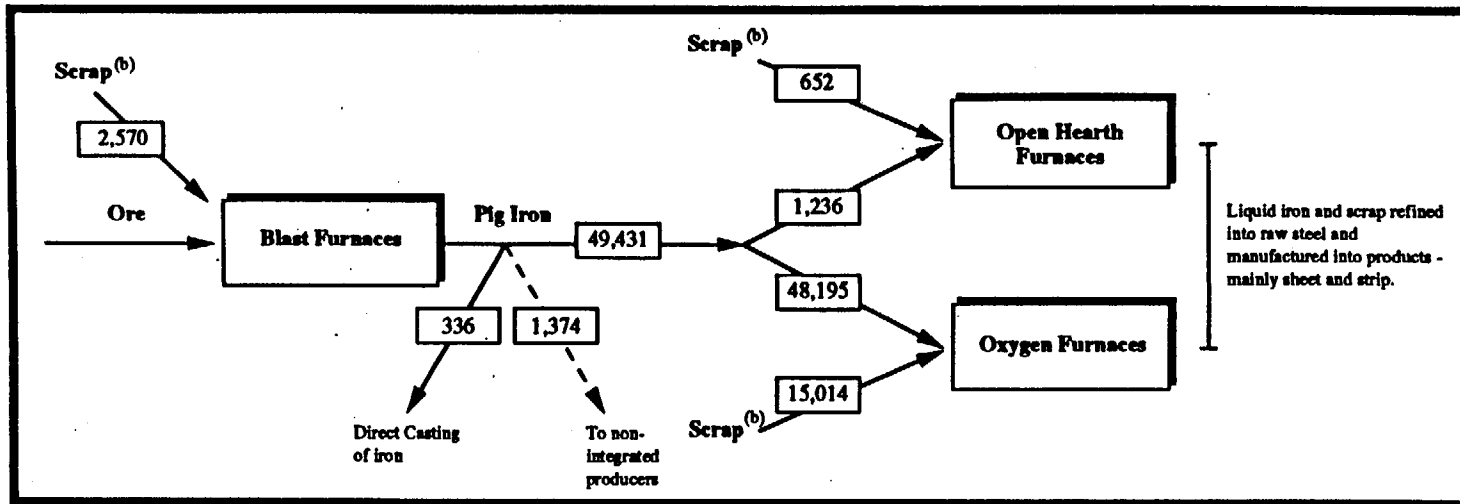
Secondary
"Nonintegrated"
Producers

Scrap[b]

34,407

Pig Iron   1,004

Electric Arc
Furnaces

Direct melting of virtually all
grades of scrap consumed by
manufacturers - mainly for
shape, plate and long products

Scrap[b]

632

Pig Iron   19

Electric Induction
Furnaces

Scrap consumed by Foundries
to produce ductile iron or steel
for casting

Scrap[b]

8,516

Pig Iron   351

Cupola Furnaces

Iron produced by Foundries
for casting
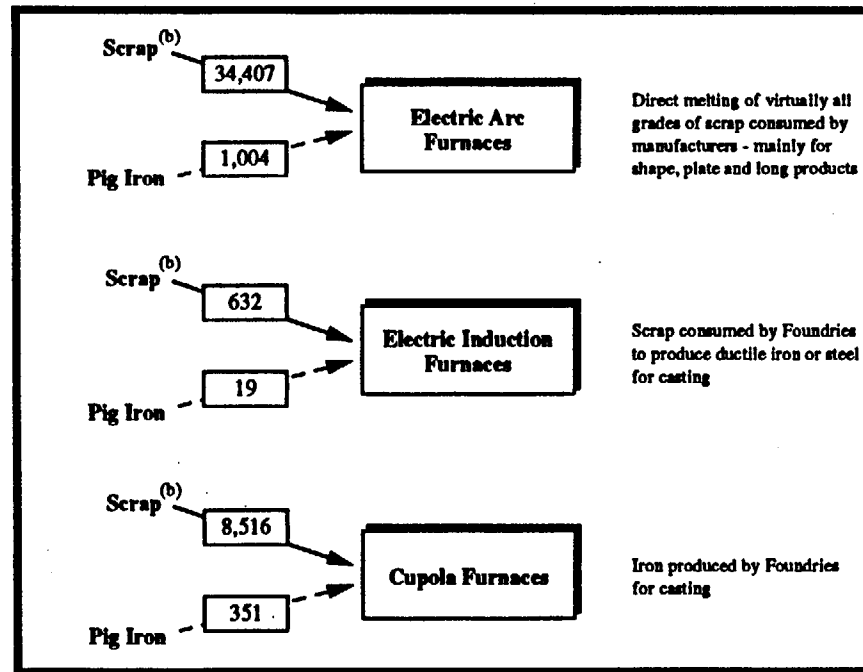
(a) Based on information in the "Iron and Steel Annual Report, 1990," and the "Iron and Steel Scrap Annual Report, 1990," US Bureau of Mines, April '92 and the "1990 Annual Statistical Report," published by the American Iron and Steel Inst

(b) Include all 3 types of scrap (home, new and old). Bureau of Mines data only reports total scrap consumed by various types of furnaces, it does not differentiate between different types of scrap

Figure 5-2: Iron/Steel Production Material Flow - 1990[a]
(Thousand Metric Tons)

Table 5-1: Salient Statistics for US Iron and Steel Production - 1990*

(Volumes reported in thousands of MT)

	1990
United States	
• Mine production of Pig Iron	49,772
• Steel production:	
- Carbon	78,718
- Stainless	1,852
- All other alloy	4,845
Total:	89,914
- Basic Oxygen Furnaces, %	59.1
- Electric Arc Furnaces, %	37.4
- Open Hearth Furnaces, %	3.5
• Continuously Cast Steel, %	67.4
• Capacity Utilization, %	84.7
• Imports of Major Steel Products	15,602
• Exports of Major Steel Products	3,912
• Net Shipments:	
- Steel Mill Products	77,255
- Steel castings	909
- Iron castings	8,363
• Average price to steel mill products (cents per lb)	26.3
World Production	
• Pig Iron	539,726
• Steel	773,620

* Data taken from "Minerals Commodity Summaries - 1992," and "Iron and Steel Annual Report, 1990." US Bureau of Mines.

Table 5-2: Raw Steel Production by Grade and Type of Furnace - 1990*

(Thousand MT)

Type of Furnace	Carbon	Alloy	Stainless	Total Shipments	Percent
Open Hearth	2,917	261	---	3,178	3.5
Basic Oxygen	48,916	4,329	---	53,400	59.4
Electric Arc	26,885	4,845	1,852	33,335	37.1
Total:	78,718 (87.5%)	9,345 (10.4%)	1,852 (2.1%)	89,913	100

*   Data taken from "Annual Statistical Report," American Iron and Steel Institute, 1990 and is for steel products only. Data was not included for Cupola and Electric Induction furnaces because they are used primarily for producing iron castings.

refining into raw steel. The integrated companies make almost exclusively "flat" products, sheet and strip. These are affected by the strength of the consumer goods markets, mainly automotive and appliances.

In 1990, basic oxygen furnaces (BOF) accounted for about 59.1% of total steel production, with open hearth furnaces accounting for only about 3.5%. At the end of 1990, there were 3 open hearth shops with 3 operable furnaces, and 25 basic oxygen shops with 58 operable furnaces. The last of the three open hearth shops are expected to be closed and replaced with BOF within the next few years (Peters, 1992).

In a BOF process rapid combustion is provided by high purity oxygen, which is blown through the roof or fed through the bottom of the furnace in controlled amounts to produce steel of the desired carbon content and temperature. The metal feed to the furnace generally contains 4.0-4.5% carbon, 0.3-1.5% silicon, 0.25-2.2% manganese, 0.03-0.05% sulfur, and 0.05-0.20% phosphorous. Oxidation is employed as the mechanism to convert a molten bath of pig iron and scrap into steel. The oxygen combines with unwanted elements (except sulfur) to form oxides that either leave the bath as gases or as slag. Various steelmaking fluxes are added during the refining process to reduce the sulfur and phosphorous contents of the metal bath to the desired level. The mechanism by which sulfur is removed does not involve direct reaction with oxygen but instead depends on the conditions of the slag (i.e., basicity, state of oxidation and temperature). The quantities of hot metal, scrap, and fluxes charged for a given heat are calculated such that at the end of blowing the prescribed oxygen, the steel bath will have the desired carbon content and temperature.

A typical BOF can process about 275 MT of steel in 45 minutes with only about 15 minutes of this time being used for the actual refining (US Steel, 1985, p.34). Most BOF consume 20-30% of the total metallic charge as cold scrap. Scrap is usually abundantly available and less expensive than hot metal, and therefore, increased scrap melting in BOF is generally a desired objective. Scrap usage in the BOF is limited, however, because the oxidation of carbon and silicon is the only source of heat for melting scrap, and scrap typically has much lower levels of carbon and silicon than pig iron. Even with preheating of scrap, the maximum amount of scrap per charge is about 40%. Home scrap produced within the mill itself is generally preferable to old scrap, since it does not affect the final quality of the steel.

Nonintegrated Steel Mills

The nonintegrated steel producers melt scrap in electric arc furnaces and cast the steel in continuous casting machines. Nonintegrated steel producers normally produce "shape" or "long" products, such as wire rods, structural shapes and bars, and the product is normally a high-strength low alloy steel. Hence, they are largely dependent on the construction industry.

For some high quality steel products direct reduced iron is substituted for scrap, in order to minimize the retention of certain residual elements such as copper and tin in the final product. The melting is controlled as an electric current arcs from one electrode, through the metallic charge in the furnace, to another electrode. Oxygen gas is injected into the bath to oxidize with alloying elements which are removed in the slag. Most electric arc furnaces are basic-lined using a complete bottom consisting of impregnated magnesite brick. About 64.8 million MT of iron and steel scrap (including home, new and old scrap) was consumed in 1990 (based on reported consumption), with about 58% being consumed by electric arc furnaces (Peters, 1992).

The electric arc furnace can refine a material charge with any ratio of pig iron to scrap, but typically operates with a solid charge of almost all scrap. This permits steel to be produced at smaller plants, referred to as "mini-mills," that are not associated with a blast furnace complex. Mini-mills typically have much lower capital investment and operating costs and the flexibility to operate at lower than full capacity. There are about 40 to 45 companies in the US that operate electric arc furnaces with the total number of furnaces being on the order of several hundred. Furnace sizes range from about 50 to 400 MT with the most common size being about 100 MT. The average processing time to melt a change of scrap in an electric arc furnace is about two hours.

Because of its flexibility with respect to charge of materials and its suitability for intermittent operation, the electric furnace is sometimes used to supplement the output of other steelmaking processes in large integrated mills in short demand peaks.

Iron and Steel Products

Domestic steel mills shipped about 77.2 million MT of products in 1990, including about 3.9 million MT that was exported. There were also about 9.2 million MT of iron and steel castings produced in 1990. In addition, about 15.6 million MT of iron and steel products were imported. The distribution of steel product shipments was reported as follows: steel service centers and distributors, 24.8% (most of this steel is ultimately used by the construction industry); construction, 14.3%; automotive, 13.1%; steel for converting and processing, 11.1%; containers, packaging and shipping materials, 5.3%; and all others, 31.4%. Tables 5-3 and 5-4 summarize the net shipments of iron and steel products in 1990 by market classification and product grades, respectively.

Table 5-3: Net Shipments of Steel Products by Market Classifications - 1990*

(Thousand MT)

Market Classification	Steel Mill Products	Percent
Steel for converting and processing	8,555	11.1
Independent forgers (not elsewhere classified)	871	1.1
Industrial fasteners	339	0.4
Steel service centers and distributors	19,192	24.8
Construction	11,104	14.3
Automotive	10,091	13.1
Rail Transportation	982	1.3
Shipbuilding and marine equipment	308	0.4
Aircraft and aerospace	30	0.0
Oil and gas industry	1,720	2.2
Mining, quarrying, and lumbering	495	0.6
Agricultural	647	0.8
Machinery, industrial equipment and tools	2,171	2.8
Electrical equipment	2,230	2.9
Appliances, utensils and cutlery	1,400	1.8
Other domestic and commercial equipment	979	1.3
Containers, packaging and shipping materials	4,067	5.3
Ordnance and other military	114	0.1
Export (reporting companies only)	2,261	2.9
Non-classified shipments	9,760	12.6
Total	77,255	100

* Data taken from "Annual Statistical Report," American Iron and Steel Institute, 1990.

Table 5-4: Net Shipments of Steel Products by Grades - 1990*

Steel Mill Products	Carbon	Alloy	Stainless	Total Shipments
Semi-finished	7.1%	12.9%	9.8%	7.4%
Shapes and plates	17.0%	9.7%	13.6%	16.5%
Rail and accessories	0.7%	---	---	0.6%
Bars	15.7%	47.1%	9.1%	17.3%
Pipe and tubing	5.1%	12.9%	2.7%	5.5%
Wire-drawn and/or rolled	1.1%	0.6%	1.5%	1.1%
Tin mill products	5.1%	---	---	4.7%
Sheets and strip	48.3%	15.6%	63.3%	46.8%
Total (thousand MT):	71,653	4,225	1,378	77,255

* Data taken from "Annual Statistical Report," American Iron and Steel Institute, 1990

5.2.1.2 Scrap Recycling Industry

Scrap Type

There are three general categories of iron and steel scrap that are used in the various steelmaking processes:

Home scrap (or revert scrap) consists of unusable products which result in the course of steelmaking and finishing operations and is always recycled. These would include pit scrap; ingots too short to roll; rejected ingots; crop ends from slabs; shear cuttings from trimming flat rolled products; pieces damaged in handling and finishing; etc. In general, about 30-35% of all iron and steel consumed in the manufacture of products becomes home scrap (Kirk-Othmer, 1983b; US Steel, 1985, p.339).

New scrap (or prompt industrial scrap) is generated by the steel consumers and is widely recycled because it is usually of high quality and its chemical and physical properties can be well documented. It may consist of unwanted portions of plate or sheet, trimmings resulting from pressing and stamping operations, machine turnings, rejected products scrapped during manufacture, flashes from forgings, etc.

Old scrap (also called obsolete, dormant or post-consumer scrap) includes all other ferrous scrap. This category includes obsolete, worn out or broken products from the consuming industries. The main types of old scrap recycled in the US are railroad, machinery, automotive, and municipal solid waste. Old scrap requires careful sorting and classification to prevent the contamination of steel in the furnace with unwanted chemical elements from alloys that may be present in some of the scrap. As a result, there are over 70 different specifications covering various grades of scrap for use in refining steel. Some manufacturers segregate their scrap into as many as 300 separate categories. About 10 million MT of scrap per year is recycled from junked automobiles and an additional 1 million MT from the steel can industry.

Scrap Consumption

All domestic production data for iron and steel scrap published by the Bureau of Mines are estimates based on monthly and annual surveys of US operations. For 1990, a Bureau of Mines internal evaluation indicated that the scrap consumption reported in its annual report was underestimated by about 8.7 million MT (Peters, 1992; AISI, 1990). For the purposes of this report, the 8.7 million MT was assumed to consist of each of the three categories of scrap in the same relative proportions as was estimated in the reported numbers. This additional "under-reported" consumption was added to the reported numbers in order to estimate total scrap consumption.

The reported total domestic consumption of ferrous scrap by the iron and steel industry, as reported by the Bureau of Mines, in 1990 was 64.8 million MT; composed of about 40.5 million MT net receipts (new and old scrap), 23.6 million MT home scrap and 0.6 million MT inventory adjustments. Scrap exports for 1990 totaled about 11.6 million MT valued at $1.64 billion, while scrap imports totaled about 1.3 million MT valued at $0.17 billion (Peters, 1992). The estimated total domestic consumption (considering under-reported consumption) for 1990 was 73.5 million MT. The apparent generation of old and new scrap in the US (net receipts plus imports minus exports) was about 56.7 million MT in 1990. Table 5-5 provides a summary of the salient statistics for iron and steel scrap. Included in Table 5-5 are estimates of total iron and steel scrap consumption which considers both estimated total domestic consumption (which includes the 8.7 million MT claimed by the Bureau of Mines), as well as reported consumption only. The consumption of iron and steel scrap (includes all types of scrap) by type of furnace is summarized in the production material flow diagram presented in Figure 5-2.

In 1990, the US Bureau of Mines reports that about 40.5 million MT of ferrous scrap valued at $4.71 billion was purchased by domestic consumers from brokers, dealers, and other outside sources (accounting for under-reporting, we estimate this number to be about 46.4 million MT). It is estimated that this scrap consists of about 60-70% old scrap with the remainder prompt industrial scrap. Steel mills (both integrated producers and mini-mills) accounted for 73% of all scrap received from brokers, dealers and other outside sources; steel foundries received 5%; and iron casting producers received 22%. Presentation of data for iron and steel scrap consumption and utilization in this report does not distinguish between new and old scrap. This is due to the nature in which purchased scrap is handled, segregated, and pre-processed. All scrap which is of similar chemical composition is combined into large bundles at the dealer sites. Thus, it is nearly impossible to distinguish between new and old scrap for most grades. Table 5-6 provides a summary of 1990 receipts of iron and steel scrap (includes both old and post-industrial scrap) from brokers, dealers, and other outside sources in the US by scrap grade, while Table 5-7 provides a regional summary of scrap receipts.

Figure 5-3 is a generalized diagram of scrap generation and recycle paths in the production of iron and steel. Old scrap pathways are indicated by dotted lines. As discussed above, consumption data reported by the Bureau of Mines does not distinguish between different types of scrap. Included in the table are estimates of scrap volumes for different paths which are important from a reuse and recycle perspective. Those numbers were estimated based on converstions with persons from the Bureau of Mines and commercial scrap processors.

Recycling and Life Cycles

Iron and steel scrap has traditionally had very little residual value, and as such, supply of iron and steel scrap far exceeds demand. Because steel scrap is a demand-driven commodity, the ability to recycle a give volume of scrap depends not only on the quality of the scrap (i.e., its chemical characteristics) but also on the cost associated with

Table 5-5: Salient Statistics for US Steel Scrap - 1990*

(Thousand MT and Thousand Dollars)

	1990
• Apparent consumption	73,491 /e
- Net receipts of purchased scrap (includes both old and new scrap)	46,433 /e
- Home scrap	27,058 /e
• Reported consumption	64,791
- Net receipts of purchased scrap (includes both old and new scrap)	40,515
- Home scrap	23,613
- Miscellaneous (includes receipts of scrap from company owned plants and changes in inventory)	663
• Exports	
- Scrap	11,605
- Value	$1,635,218
• Imports	
- Scrap	1,312
- Value	$171,510
• Apparent generation of old and prompt industrial scrap in the US	56,726 /e
• Scrap consumption (includes home, new and old scrap):	
- Basic oxygen furnaces, percent	23.2%
- Electric arc furnaces, percent	57.7%
- Open hearth furnaces, percent	1.0%
- Electric induction furnaces, percent	1.0%
- Cupola furnaces, percent	13.1%
- Blast furnaces, percent	4.0%

*   Data taken from "Iron and Steel Scrap Annual Report, 1990," US Bureau of Mines, April 1992.

/e   Bureau of Mines data is understated by about 8.7 million MT according to internal evaluation. Scrap consumption data reported here is postulated to include the unreported 8.7 million MT.

Table 5-6: Consumption of Iron and Steel Scrap by Grade - 1990*
(Thousand MT)

Scrap Grade	Consumption†	Percent
Carbon Steel:		
• Low phosphorous plate and punching	2,103	4.6
• Cut structurals and plate	2,547	5.6
• No. 1 heavy melting steel	7,711	16.9
• No. 2 heavy melting steel	3,555	8.8
• No. 1 and electric furnace bundles	5,365	11.8
• No. 2 and all other bundles	965	2.1
• Electric Furnace, 1 foot and under (no bundles)	103	0.2
• Railroad rails	475	1.0
• Turnings and borings	1,367	3.0
• Slag scrap (Fe content)	953	2.1
• Shredded or fragmentized	3,759	8.3
• No. 1 busheling	1,860	4.1
• All other carbon steel scrap	4,428	9.7
Total Carbon Steel:	35,301	77.5
Stainless Steel:	564	1.2
Alloy steel (except stainless)	201	0.4
Ingot mold and stool scrap	456	1.0
Machinery and cupola cast iron	1,075	2.4
Cast-iron borings	593	1.3
Motor blocks	431	0.9
Other iron scrap	885	1.9
Other mixed scrap	1,007	2.2
Total Scrap:	40,515	100

* Data taken from "Annual Statistical Report," American Iron and Steel Institute, 1990

† Includes both new and old scrap.

Table 5-7: US Regional Summary of Iron and Steel Scrap Consumption - 1990*

(Thousand MT)

Region and State	Consumption of Purchased Scrap†	
New England and Middle Atlantic:		
Connecticut, Main, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	1,853	2.9%
Pennsylvania	8,614	13.3%
TOTAL:	10,467	16.2%
North Central:		
Illinois	6,938	10.7%
Indiana	8,308	12.8%
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	4,705	7.3%
Michigan		
Ohio	5,487	8.5%
TOTAL:	9,418	14.5%
	34,857	53.8%
South Atlantic:		
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	6,051	9.3%
South Central:		
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	9,306	14.4%
Mountain and Pacific:		
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	4,113	6.3%
GRAND TOTAL:	64,792	100%

*   Data taken from "Iron and Steel Scrap Annual Report, 1990," US Bureau of Mines, April 1992.

†   Based on reported consumption of home, new and old scrap.

Mined metal
(ore)

49,772

"Integrated" Primary
metal producers

*this includes mining
and reduction of
iron ore into steel,
as well as
processing of the
metal into a form
suitable for
manufacturing
(usually sheet or
strip)*

"Nonintegrated"
Secondary metal
producers (mostly
scrap)

Processing of metal
for manufacturing
*(usually wire rods,
shapes, bars, etc.)*

Home scrap

Home scrap

Consumers of processed metal
(manufacturers of end products)

89,914

End products

New scrap

* 21,597

Old scrap

* 43,194

Scrap Dealers

Scrap Dealers

US Steel
Reservoir

———————————
* Numbers are estimated based on assumption that
2/3 of reported scrap consumption is old scrap

**Figure 5-3: Generalized Diagram of Recycle Paths for Iron and Steel Scrap
(Thousand MT of Recoverable Steel Content)**

delivering the scrap to the recycler. Because of the low recycle value for most grades of iron and steel scrap, data for the consumption of old scrap is not as widely available as it is for many other metals which have a higher residual value, such as aluminum and copper. Since steel is a corrodible material and many of its products are rolled into flat sheets, this results in a short life cycle for a large number of steel products, which discourages recycling. In a general sense, the recycling rate for building steel and reinforced concrete is at least 30 to 50 years, while steel that goes into white goods (commercial products) may have a life expectancy between 10 and 15 years (Brown, 1992).

5.2.1.3 Factors Relevant to Cost Benefit Studies

Production Data

A Bureau of Mines study estimates that the quantity of ferrous scrap (all types) consumed in the US by integrated and mini-mill steel producers in order to produce 1 ton of raw steel has risen from about 0.51 ton in 1970 to 0.61 ton in 1990 (Brown, 1992). This is due mainly to advances in continuous casting technology which is a more efficient forming technology than ingot casting and results in less generation of home scrap. In 1990, 67.4% of all steel was continuously cast. This increased utilization of continuous casting over ingot casting has resulted in increased steel mill processing yields and less generation of home (internally generated) scrap. Generation and consumption of home scrap in US steel mills has decreased from about 60% of all scrap in 1970 to about 27% in 1990. This trend is expected to continue and result in an increased demand for old scrap (Brown, 1992).

Occupational Injury Data

The American Iron and Steel Institute (AISI) publishes data for the rates of occupational injuries for employees engaged in the production of iron and steel products. Based on those data, the frequency of occupational death is about 3.3E-04 per year or 8.0E-05 per work year (assuming 2,000 work hrs/yr). Table 5-8 provides a summary of the data reported to AISI for 1990.

Energy Requirements and Productivity

It has been estimated that the average number of man-hours required per ton of steel produced in the US steel industry in 1990 was about 3.5 (AMM, 1987).

Various studies have estimated the processing time and energy requirements associated with processing pig iron and scrap in BOF and electric arc furnaces. A typical BOF can process 300 tons of steel in 45 minutes with only about 15 minutes of this time being used for the actual refining (US Steel, 1985, p.34). A sample calculation for a typical

**Table 5-8: Summary of Occupational Injury/Illness Data for the Production
of Iron and Steel Products - 1990***

		1990
1.	Aggregate number of man-hours (millions)	321
2.	OSHA recordable injuries/illnesses:	
	a. Fatalities	12
	b. Low workday cases	7,204
	c. Other medical treatment cases	14,014
	d. Total (2a through 2c)	21,230
3.	Frequency rate (# injuries/illnesses per 200,000 man-hours worked)	13.2
4.	OSHA workdays lost (thousands)	202
5.	Severity rate (lost workdays per 200,000 man-hours worked)	159

* Data taken from "Annual Statistical Report," American Iron and Steel Institute (AISI).

electric arc furnace to process 72.6 MT of light density scrap into mild carbon steel indicates the following: a power requirement of about 520 kW-hr per MT, a scrap yield of about 89%, and a 2 hour processing time (US Steel, 1985, p.663). Another source, estimates a power requirement of about 500 kWt per ton, with energy requirements of about 2,200 kW-hr per ton (Kirk-Othmer, 1983c).

5.2.1.4 Factors Relevant to Worker Exposure Scenarios

Standards Relating to Work Health and Safety

The Code of Federal Regulations (CFR) 29 Part 1910, Section 1000 provides limits for airborne contaminants for toxic and hazardous substances that may affect workers' safety. With respect to the processing of iron and steel scrap, the applicable standards are that the time-weighted average (over eight hours) of an employee's airborne exposure to all particulates shall not exceed 15 mg/m^3 to total dust inhalation and 5 mg/m^3 for a respirable fraction. In addition, for iron oxide fumes there is a short term exposure limit (15 minute time-weighted average) of 10 ppm.

Byproduct Material

All of the emissions of volatized gaseous metals that are generated during the refining of iron and steel are ventilated and processed in the "baghouse." All dust that is generated is treated as toxic hazardous waste. Due to the high content of zinc and other valuable chemicals, some of the dust that is generated is reprocessed to concentrate these metals. Most plants have wet processes on-site which form dust material into concrete for disposal in landfills. In addition, new processes have been recently developed which involve vitrification with the resulting products used in the construction industry. In all, about 80% of all dust generated is recycled in some form to avoid landfill disposal.

The slag that is generated during iron and steel refining is not considered toxic, since it falls below certain levels prescribed by EPA. This material is reprocessed and used in commercial applications such as road construction., etc.

Contaminated Scrap

Though there are many different radioactive materials that are potential scrap metal contaminants, much of the radioactivity encountered in scrap handling is considered "naturally occurring radioactive material" (NORM). Scrap containing NORM can be found in the scale that attaches to crude oil transmission pipe walls or to oil drilling pipe as the pipe passes through oil basin depths (radium is the most common contaminant). Radiation levels in drilling

pipe can be quite high, but this class of scrap is not covered by any Federal, and only a few state, disposal regulations (Modern Casting, 1991).

Most refiners have radiation detectors for incoming material that are set just above background (Modern Casting, 1991). There are about 30 railcars worth of slightly contaminated radioactive material that has been detected when entering refineries that now has no place to go (i.e., it cannot be processed and the landfills will not take it) (Wieczorowski, 1993). It has been estimated that daily there is anywhere from one to five railcars or trailer loads of scrap being rejected or found with radioactivity in the US. More than 75% of the times a radiation detector goes off at a site, there is no perceivable radiation source and when the material is tested it is usually revealed to be NORM (NRC, 1990). There have been a smaller number of incidents where sealed sources have been detected. Most of these sealed sources have come from industrial applications (i.e., smoke detectors, static eliminators, etc.)

The cost of disposing of this material as hazardous waste is prohibitively high and the refining industry is lobbying for the implementation of some sort of standard that would allow them to melt small amounts of contaminated material (below some prescribed level) as a small percentage of each charge in order to get rid of it.

At the other extreme, there have been several significant and highly publicized incidents (probably about one per year) where a radioactive source entered a refinery undetected and was processed. In a recent study for the years 1985-1989, 30 responding states reported 92 incidents of radioactive materials found in steel scrap, melted in a steel making facility, or contained in slag or other byproducts of steel or aluminum smelting and foundry operations (Kerr, 1990). Of the seven most recent contamination events reported in a recent trade magazine, five involved industrial gauges (containing elements such as ^{137}cesium, ^{60}cobalt, ^{226}radium, or ^{241}americium) mixed with or affixed to scrap. It has been estimated that there are about 500,000 radioactive gauging devices in the US. These devices are used by the public under licensed exemptions from NRC requirements and they present the greatest contamination threat because of their sheer numbers and the amount of radioactive materials they contain (Modern Casting, 1991).

These incidents have ended up costing the steelmakers on the order of several million dollars per incident, because the melting of the source has caused contamination in the baghouse and associated ductwork, etc. which then had to be replaced. In 1983, for example, about 25 curies of Cobalt 60 were inadvertently mixed in metal scrap at a steel mill and smelted. The cost for decontaminating this facility and disposing of the waste exceeded four million dollars. Since then, there have been other instances of accidental smelting, both in the US and abroad, with the disposal costs reaching over one million dollars in each facility (NRC, 1990).
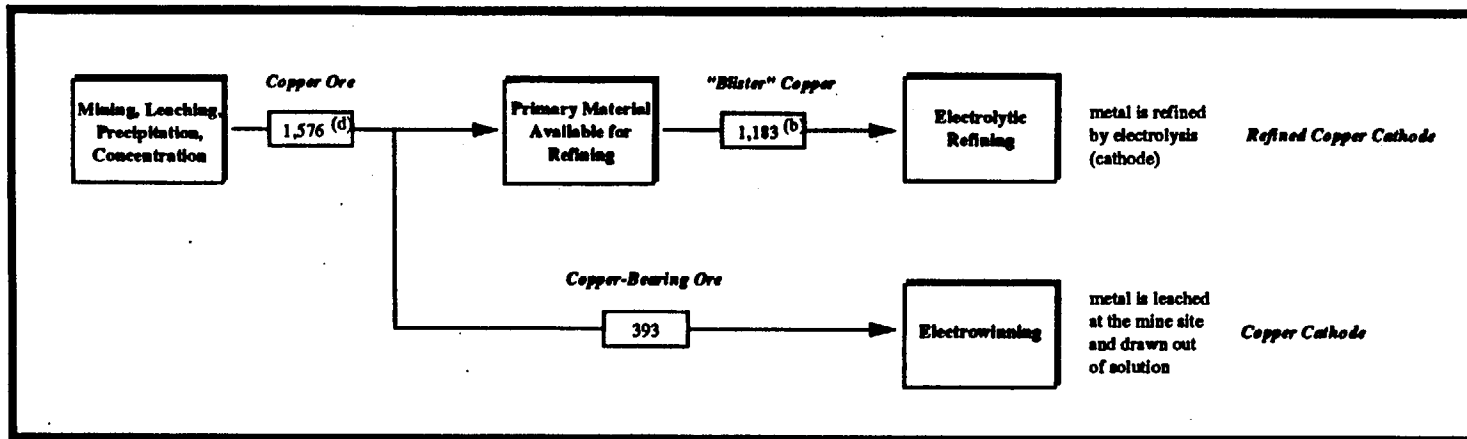
5.2.2 Copper Recycling Industry

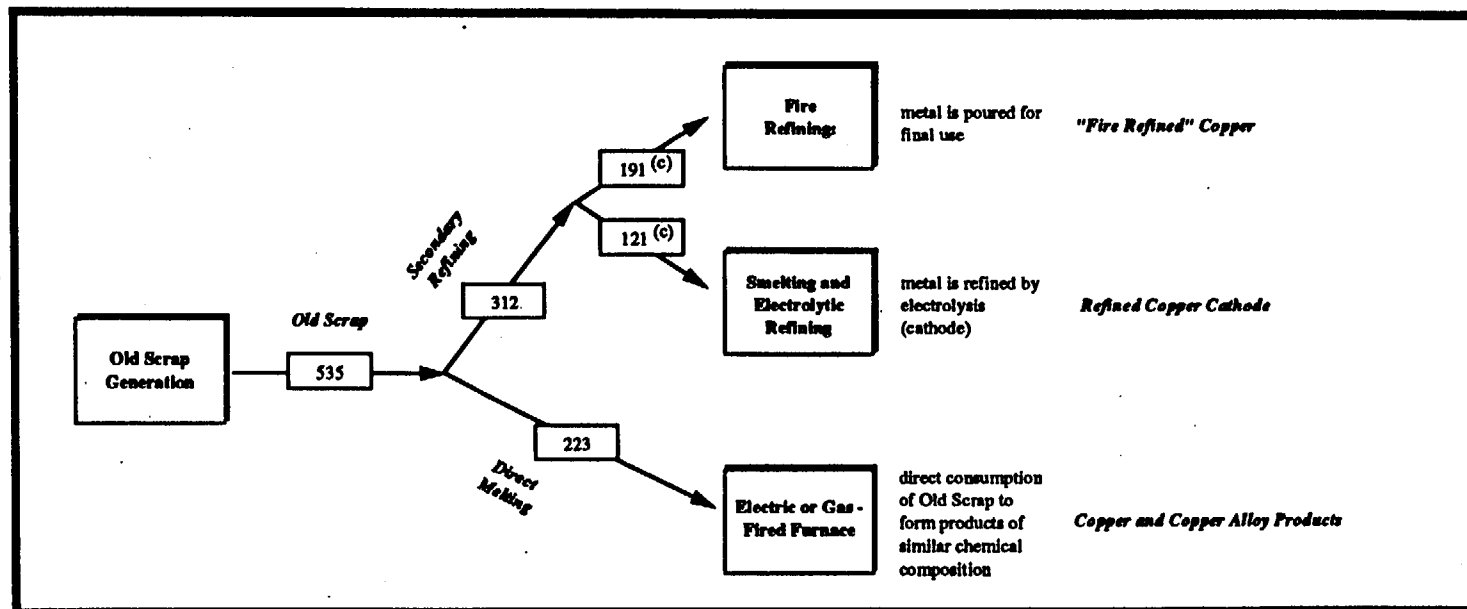### 5.2.2.1 Overview of Domestic Production and Use

There are over 370 recognized copper and copper alloys that are produced and are in use in this country. These alloys are divided into broad categories of wrought and cast metals. The major classes are: coppers, which contain greater than 99.3% copper; high copper alloys, which contain at least 94% copper; brasses, which contain zinc as the primary alloying agent; bronzes, which contain tin as the primary alloying agent, but also contain other metals; copper-nickels, which contain nickel as the primary alloying metal; leaded coppers, which are cast alloys containing at least 20% lead, but no zinc or tin; and special alloys, which are copper alloys not covered in the above group (Jolly, 1992).

According to the US Bureau of Mines, domestic mine production of copper ore in 1990 was about 1.6 million MT valued at over $4.3 billion (Jolly, 1992). Most copper concentrates are processed through a three stage smelting process to produce an enriched copper melt (usually 97% to 98.5% copper) known as "blister copper." Implicit in the smelting process is a stage where the blister is fire refined by oxidation for removal of the impurities in a reverbatory furnace. The fire refining process uses oxidation, fluxing, and reduction, and a refined ingot, wirebar, slab or billet is usually poured. The reduction is accomplished by partly covering the molten metal with coke and inserting green wooden poles through the furnace door. Copper oxide in the melt is converted to copper by the reducing gases formed. The end product is then normally cast into anode shape and further treated in an electrolyte bath to form "refined copper cathode" through electrolysis. Alternatively, copper cathode can be obtained directly from an electrowinning process, where copper cathode is plated directly from copper-bearing solutions leached at the mine site through solvent extraction methods. Secondary copper, or scrap, can either be refined or directly melted into usable form (there is a single facility which processes copper scrap by electrowinning, however, it did not begin operation until 1991). The secondary refining of copper is normally performed through electrolysis using the same process as for primary copper. A smaller amount of secondary copper is processed by fire refining and directly cast into usable form for processing. Similar to the primary fire refining this process uses oxidation, fluxing and reduction, however, instead of an anode, a refined ingot, wirebar, slab or billet is usually poured. For applications where the scrap composition is fairly homogeneous, scrap can be directly melted in an electric or gas fired furnace to form products of similar chemical composition. There is also a very small amount of old scrap that is used in the smelting of primary refined copper, mainly for cooling the copper of the copper melt. This amount of scrap is so small that it is not considered in the material flow presented in this report. Figure 5-4 provides an overview of the relationship between various processes that are used to refine copper ore and scrap into copper products. Included in this figure are estimates of copper production material flow for each process. Table 5-9 provides a summary of the salient statistics for US copper production in 1990.

"Primary" Refining:

Mining, Leaching, Precipitation, Concentration → Copper Ore 1,576 [d] → Primary Material Available for Refining → "Blister" Copper 1,183 [b] → Electrolytic Refining → metal is refined by electrolysis (cathode) → *Refined Copper Cathode*

Copper-Bearing Ore 393 → Electrowinning → metal is leached at the mine site and drawn out of solution → *Copper Cathode*

"Secondary" Recovery:

Old Scrap Generation → Old Scrap 535 → Secondary Refining 312 → 191 [c] → Fire Refining → metal is poured for final use → *"Fire Refined" Copper*

121 [c] → Smelting and Electrolytic Refining → metal is refined by electrolysis (cathode) → *Refined Copper Cathode*

Direct Melting 223 → Electric or Gas - Fired Furnace → direct consumption of Old Scrap to form products of similar chemical composition → *Copper and Copper Alloy Products*

(a) Unless otherwise indicated, material flows based on information in the "Copper Annual Report, 1990," US Bureau of Mines, April '92.
(b) This number includes a small amount of imported fire refined copper.
(c) These numbers are estimated. Bureau of Mines Copper Annual Report Table 22 data indicates that 70.7% of all copper-base scrap (new and old) consumed in refining is old scrap. This percentage was multiplied by the total scrap consumption for each type of furnace to estimate old scrap consumption.
(d) This number represents the total volume of primary material available for processing, considering mine production, imports, exports, stocks, etc. This number does not represent total mine production.

Figure 5-4: Copper Production Material Flow - 1990 [a]
(Thousand Metric Tons of Recoverable Copper Content)

Table 5-9: Salient Statistics for US Copper Production - 1990*

(Thousand MT)

	1990
United States	
Mine production	1,587
Primary refinery production	1,577
Primary refined cooper from scrap (new and old)	· 441
Old scrap generation	535
Exports: Refined	211
Unmanufactured	780
Imports: Refined	262
Unmanufactured	512
Consumption of refined copper (reported)	2,150
Apparent consumption of refined copper†	2,168
Price: (weighted avg., cathode, cents/lb, producers)	123.16 ·
World	
Mines	8.815
Smelters	9,378
Refineries	10,642
Price: (London, grade A, avg. cents/lb)	121.02

*   Data taken from "Minerals Commodity Summaries - 1992," and "Copper Annual Report, 1990," US Bureau of Mines.

†   Defined as primary refined production + copper from old scrap + refined imports - refined exports ± changes in stocks.

The principle states for copper mining are: Arizona (61% - 13 mines); New Mexico (18% - 2 mines); and Utah (14% - 1 mine). For primary refining of copper, there are currently 9 primary smelters, 8 electrolytic furnaces, and 14 electrowinning plants. Although Figure 5-4 indicates that there was a small amount of primary fire refined copper produced in 1990, there are currently no operating fire refining operations in the US. For secondary refining of copper scrap, there are 6 operating fire refineries, and 2 electrolytic refiners (Jolly, 1993b).

US Bureau of Mines statistics report that about 2.15 million MT of refined copper was consumed in 1990, including about 441 thousand MT new and old scrap used in primary and secondary refineries. Overall, there was about 0.535 million MT of old copper scrap consumed, and 0.774 million MT of new copper scrap consumed (Jolly, 1992).

Copper Products

The major categories of processing consumers for refined copper and copper scrap are: refineries, wire rod mills, brass mills, chemical plants, ingot makers and foundries. In 1990, there were about 20 operating wire rod mills, 41 brass mills, 28 ingot makers, and over 700 foundries, chemical plants and miscellaneous manufacturers. Table 5-10 summarizes the consumption of refined copper and copper scrap by each of the major categories of processing consumers.

Copper products are used in a number of different industrial applications, including: building construction, electrical and electronic products, industrial machinery and equipment, transportation, and consumer goods. A summary of refined copper consumption by industrial application is presented in Table 5-11.

5.2.2.2 Scrap Recycling Industry

Scrap Type

The Institute of Scrap Recycling (ISR) recognizes over 53 classes of copper and copper alloy scrap. The major unalloyed grades of scrap are No. 1 copper which contains greater than 99% copper and is usually remelted, and No. 2 copper which contains 94.5 - 99% copper which usually must be refined.

Scrap Generation

In 1990, an estimated 1.6 million MT of copper-base scrap, containing an estimated 1.3 million MT of copper, was consumed in the US. Copper-base old scrap consumption was about 0.535 million MT while copper-base new scrap consumption was about 0.774 million MT (Jolly, 1992). Of the total of 0.535 million MT of copper-base old scrap

Table 5-10: Consumption of Refined Copper and Copper-Based Old Scrap
by Processing Consumers - 1990 (Metric Tonnes)[a]

	Refined Copper Consumption		Cu-Based[b] Old Scrap Consumption	
Refineries	---	(0.0%)	311,150	(62.0%)
Wire Rod Mills	1,653,490	(76.9%)	32,626[c]	(6.5%)
Brass Mills	445,200	(20.7%)		
Chemical Plants	1,086	(0.05%)	2,404	(0.5%)
Ingot Makers	4,479	(0.2%)	123,850	(24.7%)
Foundaries	14,550	(0.7%)	31,650	(6.3%)
Miscellaneous[d]	31,601	(1.5%)	---	(0.0%)
	2,150,426	(100%)	502,040	(100%)

(a)   Material flows based on information in the "Copper Annual Report, 1990," US Bureau of Mines, April 1992.

(b)   Scrap volume estimates are based on copper-based scrap only; the total volume of copper recovered from all scrap in 1990 is somewhat higher (535,372 for old scrap).

(c)   Available data does not differentiate between wire rod and brass mills.

(d)   Includes iron and steel plants, primary smelters producing alloys other than copper, consumers of copper powder and copper shot, and other manufacturers.

Table 5-11: Apparent Consumption of Refined Copper by End
Use Sector - 1990*

Industrial Application	Cu Consumption	
	(x1000 MT)	(Percent)
Electrical	1,561	72
Construction	325	15
Industrial Machinery and Equipment	108	5
Transportation	87	4
Ordnance	22	1
Other Uses	65	3

*   Data compiled by the Copper Development Association (CDA). The electrical component has been extracted from all end-use categories except electrical and ordnance. Ordnance reflects US Department of Commerce ACM military shipments.

that was consumed in 1990, about 0.502 million MT or 93.8%, came from copper-base metals. Of the remaining old scrap, about 6.1% came from aluminum-base metals, with the remainder coming mainly from nickel-base and zinc-base metals (Jolly, 1992).

Figure 5-5 is a generalized diagram of scrap generation and recycle paths in the production of copper. Old scrap pathways are indicated by dotted lines. As shown in the figure, old scrap is either consumed by secondary smelters or directly remelted into end-products by the manufacturers. For the most part, old scrap is not consumed by the primary refiners. The figure also indicates that generation of recyclable copper old scrap in the nuclear industry in 1990 was less than 1% of the annual old scrap utilization for copper.

Scrap Process Technology

Most old scrap which is recovered must be refined into a usable form for processing. Of the 0.535 million MT of old copper scrap that was generated in 1990, about 0.223 million MT was directly remelted and the remaining 0.312 million MT was refined, with about 0.191 million MT fire refined and the remaining 0.121 million MT processed by smelting and electrolysis, as indicated in Figure 5-3. Beginning in 1991, there is also a small amount of copper scrap that is processed through electrowinning.

For the refining of copper scrap, there are currently 6 operating fire refineries in the US with a total capacity of 0.196 million MT, 5 secondary smelters with a total capacity of about 0.436 million MT, 2 electrolytic refiners with a total capacity of 0.2 million MT, and 1 electrowinning plant with a capacity of 0.09 million MT. Most impure old copper scrap from sources such as radiators, electronics, cable or tubing is generally processed by smelters and refiners fall into this category. Table 5-12 provides a summary of the location and capacity of each of the secondary refining facilities in the US.

Nearly all of the scrap that was remelted was alloy scrap which was processed into material of similar chemical composition. In most cases, scrap melters are located alongside the manufacturing process (i.e., brass and wire rod mills). As such, the number and location of scrap melters was not readily available information.

Special processes are used in the recycle of electronic scrap, due to the complexity of the material which may include large amounts of plastics, organic flame retardants and ceramics; further, the relatively high gold and silver content in such scrap makes this scrap economically attractive. A number of different processing techniques are employed including: mechanical dismantling by crushing and separation by means of density or conductivity, thermal dismantling, and various solvent extraction and electrowinning techniques.

Mined copper
ore

312

1,576

Primary refiners
(mining and
reduction of metal)

Secondary smelters
and refiners (use
exclusively scrap)

Processing of metal for manufacturing
(i.e., brass and wire rod mills, ingot makers)

Home scrap

2,150

223

Consumers of processed metal & manufacturers
of end products
(rolling mills, foundries, chemical plants)

Home scrap

End products

New scrap

773

Old scrap

Scrap dealers

≈1,100 /yr

Scrap dealers

535 *

US Copper
Reservoir

≈65,000 in 1990

* *Generation rate of recyclable copper old scrap in the nuclear
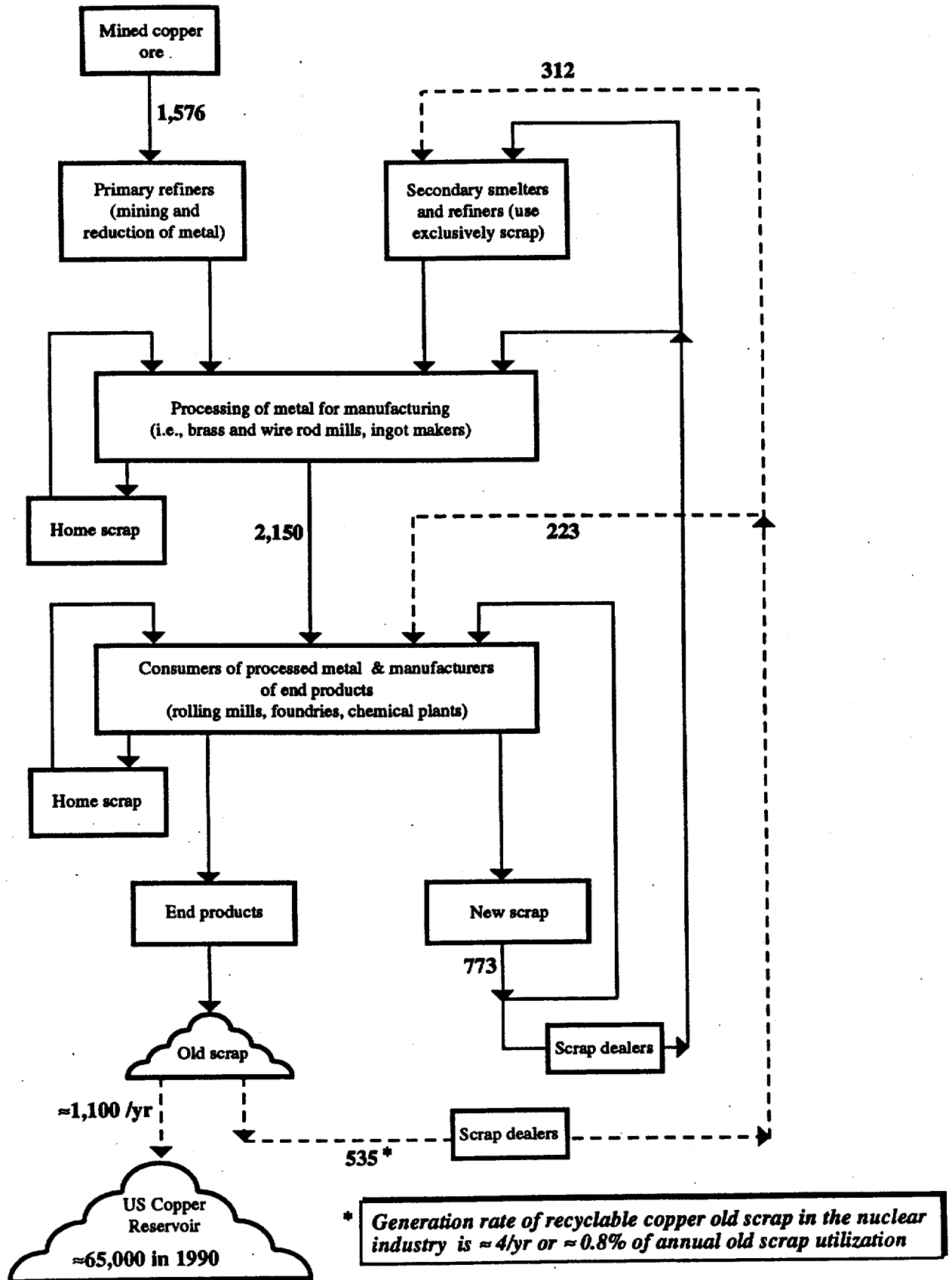industry is ≈ 4/yr or ≈ 0.8% of annual old scrap utilization*

Figure 5-5: Generalized Diagram of Recycle Paths for Copper Scrap
(Thousand MT of Recoverable Copper Content)

Table 5-12. Summary of Secondary Refining Capability in the US - 1991

Process	Location		1991 Capacity
Smelters:			
	Sauget, IL		70,000
	Alton, IL		135,000
	Philadelphia, PA		16,000
	Gaston, SC		110,000
	Carrollton, GA		105,000
		TOTAL:	436,000
Fire Refiners:			
	Sauget, IL		55,000
	Indiana		34,000
	Chicago, IL		500
	Reading, PA		70,000
	Philadelphia, PA		4,500
	Warrenton, MO		32,000
		TOTAL:	196,000
Electrolytic:			
	Sauget, IL		80,000
	Gaston, SC		120,000
		TOTAL:	200,000
Electrowinning:			
	Newman, IL		900

Scrap Consumption

The scrap consuming industries in the US include refiners, ingot makers, brass and wire-rod mills, foundries and miscellaneous chemical plants. The utilization of scrap (new and old) varies widely by industry. Most wire rod mills use very little scrap as direct feed without further processing. Advances in continuous cast rod technology require some mills to use very clean, high grade scrap, if used directly at all. Scrap comprises less than 5% of feed used. Brass mills are the principle consumers of No. 1 copper scrap and account for more than 75% of the copper alloy scrap intake. Nearly all of the copper raw material used to produce specialty alloy ingot for use in foundries was scrap, much of it used in a direct melting process.

Specific data for old scrap utilization is not widely available, as most data is reported in terms of total scrap consumption. More than 70% of all old scrap is consumed by the primary refiners and ingot makers, consisting largely of No. 2 copper and recycled automobile radiators. Most of the remaining old scrap is used to produce brass and bronze ingots. Fabricators, such as brass and wire rod mills, prefer to use as much clean scrap as possible to conserve on using more expensive primary refined metals. As such, typically less than 20% of their scrap consumption is old scrap. Table 5-13 estimates the consumption of copper-based old scrap by scrap type and processor in 1990. It should be noted that numbers reported in Table 5-12 are for copper-base scrap only (aluminum-base and other metal scrap containing copper are not included). Based on these estimates, the largest old scrap categories were: No. 2 copper, 35.8%; cartridge cases and brass, 13.5%; automobile radiators, 13.2%; No. 1 copper, 11.1%; low grade residues, 8.5%; and red brass, 7.9%.

Recycling and Life Cycles

The total scrap recycling rate for copper (as a percentage of total copper consumption) in 1990 was about 61%, while the recycling rate for copper old scrap by itself was about 25%. About 22% of refined copper produced in the US in 1990 was from scrap, with about 15% of refined copper production coming from old scrap.

The availability of copper scrap is linked with the quality of products consumed (i.e., their turnover rate) and their life cycles. According to one study, copper in electrical plants and machinery averages 30 years; in non-electrical machinery, 15 years; in housing, 35 years; in transportation, 10 years; and in all other end use sectors about 10 years. The average for the entire industry was about 25 years (Olper, 1984, p.36).

Table 5-13: Estimated Consumption of Copper-Base Old Scrap by Scrap Type and Processor - 1990*

(MT Gross Weight)

Scrap (Grade)	Estimated Old Scrap Consumption† [Values in () represent Percent of Old Scrap vs. Total Scrap Consumption]				
	Smelters, Refiners and Ingot-Makers	Brass Mills and Wire Rod Mills	Foundaries, Chemical, and Manufacturers	Total	Percent of Total Old Scrap
No. 1 Copper	38,429 (29)	18,364 (7)	23,349 (69)	80,142 (19)	11.1
No. 2 Copper	238,825 (88)	14,859 (23)	5,020 (71)	258,704 (75)	35.8
Total Unalloyed Scrap	*277,254*	*33,223*	*28,369*	*338,846 (44)*	*46.9*
Red Brass	42,745 (84)	4,289 (60)	10,124 (60)	57,158 (76)	7.9
Leaded Yellow Brass	2,636	24,006	399	27,040 (12)	3.7
Yellow and Low Brass	- -	- -	- -	14,912 (12)	2.1
Cartridge Cases and Brass	- -	- -	- -	97,726 (100)	13.5
Auto Radiators	87,885 (100)	N/A N/A	7,062 (100)	94,947 (100)	13.2
Bronzes	11,108 (100)	0 (0)	N/A (100)	11,108 (60)	1.5
Ni-Cu Alloys	- -	- -	- -	3,195 (15)	0.4
Low Grade Residues	61,511 (45)	N/A N/A	N/A N/A	61,511 (45)	8.5
Other Alloys	23,358 (50)	7,744 (50)	N/A N/A	15,551 (50)	2.2
Total Alloyed Scrap				*383,149 (46)*	*53.1*
Total Scrap				*721,995 (45)*	*100.0*

* Scrap consumption based on information in the "Copper Annual Report, 1990," US Bureau of Mines, April 1992. Volume estimates represent gross weight of scrap and not copper weight.

† Old scrap consumption wasn't available for 1990; values in () were estimated based on old scrap utilization for 1989.

5.2.2.3 Factors Relevant to Cost Benefit Studies

Cost Studies

There have been various studies which have estimated the energy costs of refining. One study estimated the cost of producing secondary copper to be about half the cost of producing primary copper. Excluding the energy content of the materials used, which can be estimated to be about 5 Gj per ton, refined copper from ore would require about 70 Gj of total energy, while to recover pure copper from scrap would require only about 35 to 40 Gj per ton (Olper, 1984, p.36). Another source estimated 117.9 Gj (28.2 million Kcal) per ton for producing primary copper from ores and only 18.8 Gj (4.5 million Kcal) per ton for producing secondary copper (Shamsuddin, 1986). Another source estimates energy consumption of about 45 Gj per ton for smelting and refining of low grade scrap, and only about 5 Gj per ton for direct remelting and casting of scrap (Kirk-Othmer, 1983a).

Copper Generation Rate

The US reservoir of copper materials in use, or abandoned in place, was estimated to be about 63.5 million MT in 1991, increasing since 1983 at a rate of about 1.1 million MT per year (Carrillo, 1974). However, another Bureau of Mines Study predicted the annual increase in unrecovered copper to increase to over 2.2 million tons by the year 2000 (Olper, 1984, p.30-36).

5.2.2.4 Factors Relevant to Worker Exposure Scenarios

Standards Relating to Worker Health and Safety

The Code of Federal Regulations (CFR) 29 Part 1910, Section 1000 provides limits for airborne contaminants for toxic and hazardous substances that may affect workers' safety. With respect to the processing of copper scrap, the applicable standards are that the time-weighted average (over eight hours) of an employee's airborne exposure to copper shall not exceed 0.1 mg/m^3 for fumes, and 1 mg/m^3 for copper dusts and mists.

In addition, 29 CFR Part 1910, Section 1025 provides limits for airborne lead contamination that applies to brass and bronze ingot manufacturers, lead chemical manufacturers, secondary copper smelters, and non-ferrous foundries. For lead, the time-weighted average (over eight hours) of an employee's airborne exposure shall not exceed 50 μg/m^3.

Uses of Slag

Large quantities of slags are produced in copper smelting plants. Depending on the ore and scrap quantity being processed, up to 4 tons of reverbatory slags will be generated in the production of one ton of copper (Jolly, 1993a). Limited space in many plants has encouraged continuing research activities into finding uses for slag. Some uses have included: railroad ballast, aggregate for roadmaking, soil conditioners, slag wool, a porous aggregate for light weight concrete, etc. These products are only processed when the metal content of the slag is below applicable standards.

Other Regulatory Issues

Some other regulatory issues that have been identified include:

- Recently there has been strict legislation of the emissions associated with the incineration of lead-containing plastic wire coverings and fluff. This has lead to increased use of mechanical dismantling of cable. An estimated 340,000 tons of cable are chopped every year in the US resulting in about 158,000 tons of plastic waste that must be disposed of in some way. Lead-containing plastics are not recyclable and land fill costs are becoming prohibitively high.

- Proposed legislation limits lead content in alloys to 2%. Since the average copper alloy contains about 8% lead, the scrap to be used in the future will have to be diluted which will increase the cost of certain alloys. It is expected that fewer high lead copper alloys will be produced in the next decade.

- The Solid Waste Disposal Act, section 201 would deem as hazardous waste any discarded material that contained more than 1% of any heavy metal. If passed, this could severely curtail recycling efforts for certain materials.

5.2.3 Aluminum Recycling Industry

5.2.3.1 Overview of Domestic Production and Use

Industry Structure

The world aluminum industry is composed of six large integrated firms, about 50 smaller publicly owned companies, and governments of centrally planned and market economy countries; these control about 40%, 25%, and 35% of world aluminum production capacity, respectively (US Department of the Interior, 1985).

Aluminum metal is produced in electrolytic cells through the reduction of aluminum oxide (alumina), which is refined from impure hydrated alumina found in bauxite ore.

The US is entirely dependent on foreign sources for metallurgical-grade bauxite. Major deposits of bauxite are located in countries remote from the main aluminum producing and consuming centers in North America and Europe. In 1990, over 70% of the worlds bauxite was produced in Australia, Guinea, Jamaica and Brazil. According to the US Bureau of Mines, the US imported about 12.1 million MT of bauxite in 1990 (Plunkert, 1992).

Bauxite imports are shipped to five domestic alumina plants, which produce smelter grade alumina for the US primary metal industry. These refineries are located in Texas, Louisiana and the US Virgin Islands. These five refineries are insufficient to meet the demand of the US primary metal industry, and therefore, the US must also import alumina to supplement its domestic requirements. In 1990, the US produced about 5.2 million MT of alumina at its five plants. In addition, there were an additional 4.1 million MT of alumina that was imported and about 1.2 million MT that was exported (Plunkert, 1992).

About 8.05 million MT of alumina was consumed by primary refiners to produce about 4.05 million MT of aluminum in 1990, corresponding to about 23% of world production. Figure 5-6 summarizes the aluminum production material flow for 1990, while Table 5-14 provides a summary of salient statistics for aluminum.
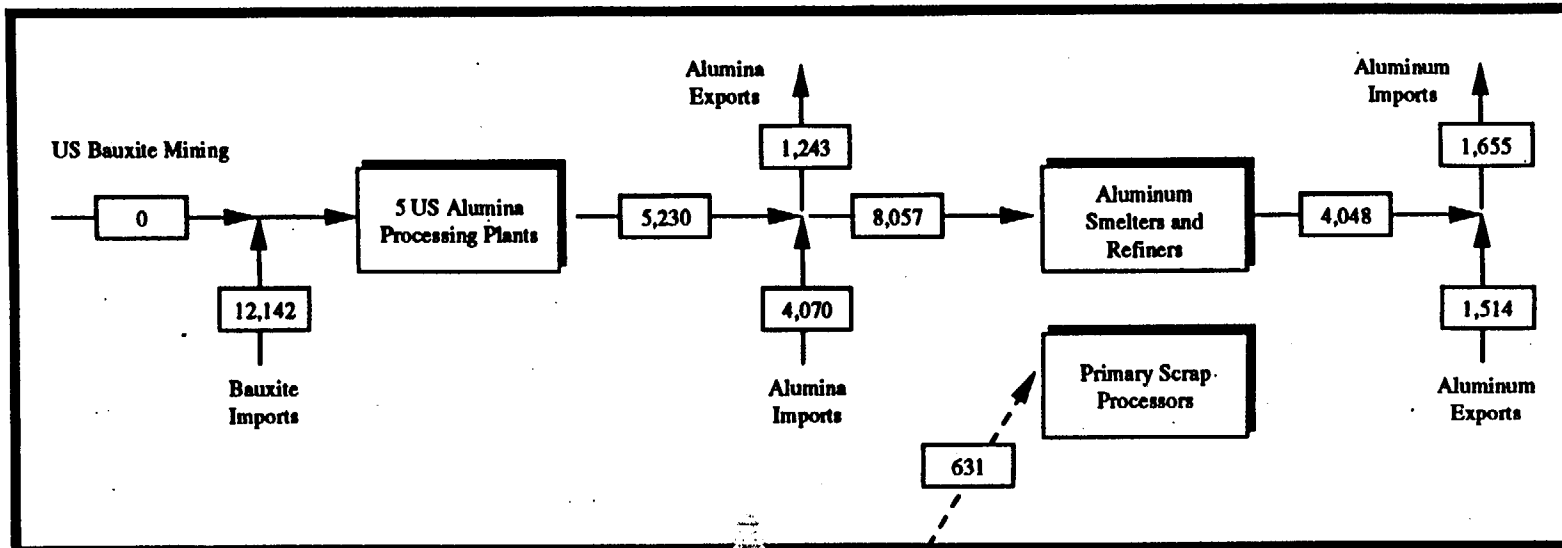
Specifications

Commercially pure aluminum usually contains about 99.7% aluminum. Aluminum is also available in strain hardened conditions of higher strength and reduced ductility. There are also over 100 commercially available aluminum alloys which are generally divided into two groups: wrought and casting. The Aluminum Association uses a code to designate the purity and alloy content of wrought alloys and to register the composition of casting alloys and ingot. The range of compositions of wrought aluminum alloys and selected casting alloys is summarized in Table 5-15.

Aluminum Consumption

The US remains the largest consumer of aluminum in the world. The container and package industry is the largest end use consumer of aluminum metal, accounting for about 28% of domestic aluminum consumption in 1990. The Can Manufacturers Institute reported that about 88 billion aluminum cans were shipped in 1990, representing about 95% of all beverage can shipments. Beverage cans with aluminum bodies, can ends and tabs accounted for more than 80% of the metal used by the containers and packaging industry.

Metal products such as residential siding, doors and windows, roofing, mobile homes, awnings and canopies, heating and ventilation applications, screening, bridges and guardrails, and other building and construction uses accounted for about 16% of total usage in 1990.

Integrated Primary Producers:

US Bauxite Mining

Alumina Exports

Aluminum Imports

| 0 |

| 12,142 |

Bauxite Imports

5 US Alumina Processing Plants

| 5,230 |

| 1,243 |

| 8,057 |

| 4,070 |

Alumina Imports

Aluminum Smelters and Refiners

| 4,048 |

| 1,655 |

| 1,514 |

Aluminum Exports

Primary Scrap Processors

| 631 |

Secondary Recovery:

Old Scrap Generation

| 1,359 |

| 582 |

Secondary Smelters

| 19 |

Foundries

| 88 |

Fabricators

| 39 |

Chemical Plants

| 539 |

Scrap Exports
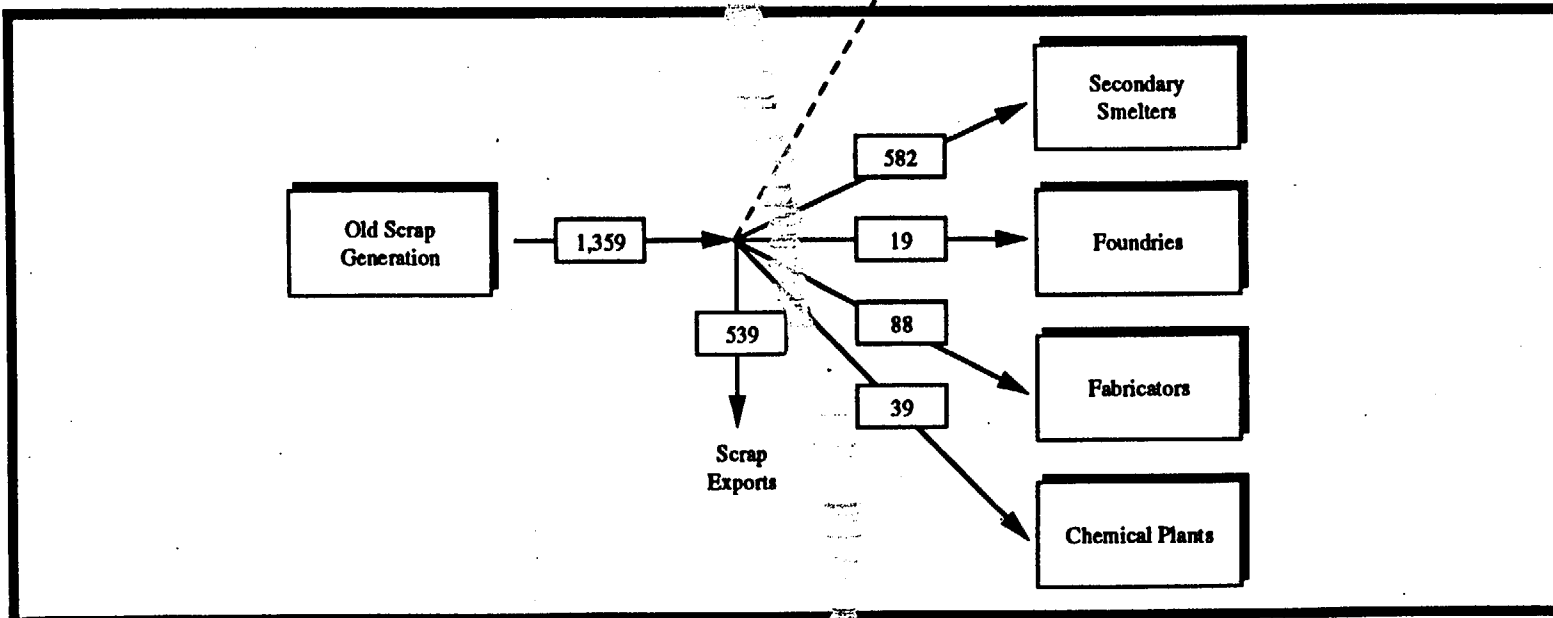
(a) Material flows based on information in the "Aluminum, Bauxite and Alumina Annual Report - 1990," US Bureau of Mines.

Figure 5-6: Aluminum Production Material Flow - 1990[a]
(Thousand MT)

Table 5-14: Salient Statistics for US Aluminum Production - 1990*

(Thousand MT)

	1990
Change in stocks	+2
Primary production	4,048
Value	$6,604,398
Secondary recovery	
- Old scrap	1,359
- New scrap	1,034
Imports for consumption (crude and semicrude)	1,514
Total Supply	7,957
Less total exports (crude and semicrude)	1,659
Available supply for domestic manufacturing	6,298
Apparent consumption†	5,264
World aluminum production	17,817

*   Data taken from "Aluminum, Bauxite, and Alumina Annual Report - 1990," US Bureau of Mines.

†   Apparent aluminum supply available for domestic manufacturing less recovery from purchased new scrap (a measure of consumption in manufactured end products).

Table 5-15: Composition Limits and Uses of Some Aluminum Wrought and Casting Alloys*

(Weight Percent)

Designation	Aluminum	Copper	Manganese	Magnesium	Silicon	Other Constituents	Applications
Wrought Alloy Series							
1000	99.0-99.75	0.2	0.05	0.05	1.0	0.1 zinc, 0.05 titanium	Electrical conductor, chemical equipment, cooking utensils
2000	Balance	1.9-6.8	0.2-1.8	0.02-1.8	0.1-1.2	1.3 iron, 0.2 titanium, 2.3 nickel	Forgings, aircraft, rocket fuel tanks
3000	do.†	0.3	0.3-1.5	0.2-1.3	0.6	0.4 zinc, 0.1 titanium, 0.7 iron	Ductwork, cable bodies, hydraulic tubing
4000	do.†	0.1-1.3	0.05-1.3	3.6-13.5	3.6-13.5	1.3 nickel, 0.2 zinc	Welding and brazing wire, pistons
5000	do.†	0.2	0.01-1.0	0.5-5.6	0.45	0.35 chromium, 0.2 titanium, 7.0 iron	Bus and truck bodies, screens, pressure vessels, aircraft tubing
6000	do.†	0.1-1.2	0.03-1.1	0.35-1.5	1.8	2.4 zinc, 1.0 iron	Heavy duty structures, pipe, bus bars
7000	do.†	0.05-2.6	0.1-0.7	0.1-3.4	0.7	0.35 chromium, 8.0 zinc, 0.2 titanium	Aircraft structurals and skins
Diecasting Ingot:							
A380	do.†	3.0-4.0	0.5	0.1	7.5-9.5	0.5 nickel, 3.0 zinc, 1.3 iron	General purpose castings
A413	do.†	1.0	0.35	0.1	11.0-13.0	0.5 nickel, 0.5 zinc, 1.3 iron	Large instrument cases
Sand and Permanent Mold Casting Ingot:							
342	do.†	3.5-4.5	0.35	1.2-1.8	1.0	2.3 nickel, 0.35 zinc, 0.25 titanium	Cylinder heads, engine pistons
356	do.†	0.25	0.35	0.2-0.4	6.5-7.5	0.6 iron, 0.35 zinc, 0.25 titanium	Automotive transmission cases, aircraft and marine fittings.

* Information taken from "Mineral Facts and Problems, 1985," Chapter for Aluminum, US Department of the Interior.

† Balance after deducting percent contribution of specified alloying constituents, plus other normal impurities.

The transportation industry was also a major consumer of aluminum metal, accounting for about 18% of total consumption in 1990. Passenger cars accounted for about one-half of transportation uses; trucks, buses and trailers one-third; with commercial and naval marine vessels, railroad cars, military and recreation vehicles composing the remainder.

Other major consumers of aluminum include the electrical industries, consumer durables, and machinery and equipment. Table 5-16 summarizes the end-use distribution of aluminum products in the US by consuming industries, based on information compiled by the Aluminum Association.

Aluminum Products

The Aluminum Association estimates that total net shipments of mill products, including imports, by domestic producers in the US amounted to about 7.2 million MT in 1990 (Aluminum Association, 1991). About 18% of shipments were in ingot form, with the remaining 82% in the form of mill products from US producers and imports. Table 5-17 provides a summary of total aluminum industry shipments, including imports and exports, for 1990.

Of all shipments of aluminum products in 1990, more than 56% were flat products in the form of sheet, plate and foil. About 17% of all products were ingot form, with an additional 17% in extrusions and billets. The remaining 7% of products were in the form of rod, bar and wire, forgings and impacts, and powder. Table 5-18 provides data on the end-use distribution of aluminum by its major products.

5.2.3.2 Scrap Recycling Industry

Scrap Type

The aluminum scrap which is recyclable can be generated either from old, discarded or obsolete material, or from scrap that is generated during the manufacturing of aluminum products.

New scrap is generated from aluminum wrought and cast products as they are processed into consumer or industrial products. New scrap classifications for aluminum include: solids, clippings and cuttings; borings and turnings (from machining operations); residues; obsolete and surplus products (mill products and castings).

Old scrap is the aluminum retrieved from "post-consumer" wastes of all types. The major categories of old scrap include: used beverage cans, automobiles, siding and roofing material, construction material, etc.

**Table 5-16: End-Use Distribution of Aluminum Products in the US
by Industry* - 1990**

(Thousand MT)

Industry	Consumption	Percent of Total
Containers and packaging	2,161	27.9
Building and construction	1,211	15.6
Transportation	1,390	18.0
Electrical	590	7.7
Consumer Durables	504	6.6
Machinery and equipment	444	5.8
Other Markets	260	3.4
Total to domestic users	6,498	85.0
Exports†	1,160	15.0
Grand Total	7,744	100
Adjusted Net Total†	7,167	- -

*   Data are taken from "Annual Statistical Review for 1991," the Aluminum Association. Includes net shipments of mill products as reported by domestic producers to the US Department of Commerce, plus imported mill products.

†   Reflects statistical adjustment made by the Aluminum Association to account for an overstatement (or understatement) in net reported shipments.

Table 5-17: Total Aluminum Industry Shipments* - 1990

(Thousand MT)

Net Shipments	Amount	Percent Total
Total	7,167†	100
Ingots	1,272	17.7
Mill products		
- US producers	5,438	75.9
- Imports	458	6.4
US exports†	1,160	16.2
US consumers	6,008	83.8

*   Data are taken from "Annual Statistical Review for 1991," the Aluminum Association. Includes net shipments of mill products as reported by domestic producers to the US Department of Commerce, plus imported mill products.

†   Includes statistical adjustment made by the Aluminum Association to account for an overstatement (or understatement) in net reported shipments. Actual net shipments of mill products as reported by domestic producers to the US Department of Commerce, plus imported mill products is somewhat higher (7.744 thousand MT).

Table 5-18: End-Use Distribution of Aluminum in the US by Major Products* - 1990

(Thousand MT)

Product	Total Shipments	Percent of Total
Sheet, plate and foil	4,391	56.7
Ingot	1,471	19.0
Extrusions and tube	1,324	17.1
Conductor	287	3.7
Rod, bar and wire	·139	1.8
Forgings and impacts	77	1.0
Powder	54	0.7
Total	7,744	100

* Data are taken from "Annual Statistical Review for 1991," the Aluminum Association. Includes net shipments of mill products as reported by domestic producers to the US Department of Commerce, plus imported mill products.

Scrap Processing

There are several hundred dealers that purchase and collect scrap from industrial sources, as well as scrap contained in discarded industrial or commercial products or from small commercial collectors, and prepare the various materials for resale. Dealers also may sometimes sort and prepare the scrap (i.e. cleaning, shearing, cutting, and grading of scrap) as required by prospective buyers. In general, the composition of well segregated aluminum-based scrap will fall within the ranges given in Table 5-15. Such scrap is then sold to the independent secondary smelters, the integrated primary producers, and others.

In recycling, aluminum-base scrap is usually melted in gas or oil fired reverbatory furnaces of 10 to 50 MT capacity, sometimes with a small amount of primary ingot material and alloying elements to control the chemical characteristics of the final product. Aluminum scrap is always processed separately from primary material, even scrap which is consumed by the integrated primary producers. The principle refining of aluminum-base scrap is the removal of magnesium by treating the molten metal with chloride, aluminum fluoride, or mixtures of sodium and potassium chlorides and fluorides (US Department of the Interior, 1985). To facilitate handling, a significant portion of the old aluminum scrap, and in some cases new scrap, is melted to form a solid ingot called "sweetened pig." Sweated aluminum is formed into ingot molds and can be sold to smelters based on analysis where it can be further treated to form specification-grade aluminum ingot.

Scrap Generation

Analysis indicates that recovered old, or post-consumer, scrap typically takes one of three major forms: (1) aluminum cans, (2) automotive scrap, and (3) municipal waste recovery scraps consisting of mixed aluminum alloys and mixed nonferrous alloys. Table 5-19 provides a listing of commonly used alloys found in consumer products, including those which are capable of utilizing large volumes of scrap recovered from consumer sources (Aluminum Association, 1985). From this table, it is clear that virtually all UBC old scrap consists of aluminum alloys 3004, 3104, and 5182. Two major groups of wrought alloys, the 3000 and the 5000 series, make up the majority of readily recoverable old aluminum scrap in municipal refuse. On a weight basis, 75-80% of the readily recoverable aluminum in municipal waste consists of three alloys - 3003, 3004 and 5182, a significant portion of this being aluminum cans. Automotive scrap includes a variety of wrought and cast alloys, as indicated in the table.

Figure 5-7 is a generalized diagram of scrap generation and recycle paths in the production of aluminum. Old scrap pathways are indicated by dotted lines. As shown in the figure, most old scrap is consumed by secondary processors either at the smelter site or by industrial processors in the production of pre-casting alloys. The remaining old scrap is in the form of used beverage containers (UBCs) which are directly remelted by the primary scrap processors in the production of new UBCs. The figure also indicates that the generation of recyclable
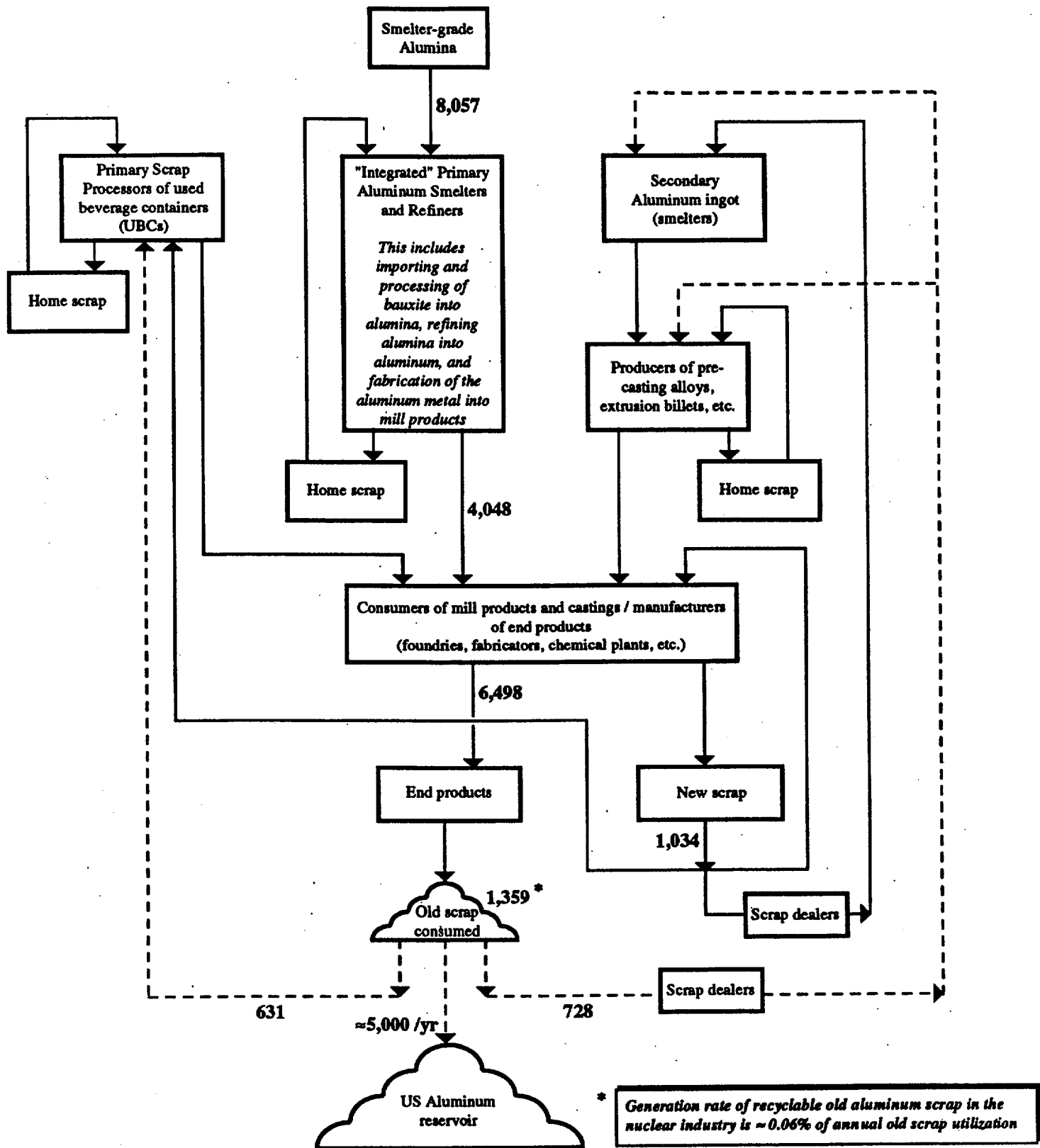
Table 5-19: Commonly Used Alloys Found in Consumer Products

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Ea.	Total	Uses
Wrought Alloys:										
1235	0.65 SI+Fe	- -	0.5	0.5	0.5	0.1	0.06	0.03	- -	Printed foil
2036	0.5	0.5	2.2-3.0	0.1-0.4	0.3-0.6	0.25	0.15	0.05	0.15	Auto body sheet
3003†	0.6	0.7	0.05-0.2	1.0-1.5	- -	0.1	- -	0.05	0.15	Cooking utensils; packaging
3004†	0.3	0.7	0.25	1.0-1.5	1.0-1.5	0.25	- -	0.05	0.15	Can bodies
3005†	0.6	0.7	0.3	1.0-1.5	1.0-1.5	0.25	0.1	0.05	0.15	High strength residential building material
3104	0.6	0.8	0.05-0.25	0.8-1.4	0.8-1.4	0.25	0.1	0.05	0.15	Can bodies
3105†	0.6	0.7	0.3	0.3-0.8	0.3-0.8	0.4	0.1	0.05	0.15	Residential building material
5052	0.25	0.4	0.1	0.1	0.1	0.1	- -	0.05	0.15	Appliances; truck trailer
5182†	0.2	0.35	0.15	0.2-0.5	0.2-0.5	0.25	0.1	0.05	0.15	Can ends; auto body sheet
5657	0.08	0.1	0.1	0.03	0.03	0.05	- -	0.2	0.05	Bright auto trim
6063	0.2-0.6	0.35	0.1	0.1	0.1	0.1	0.1	0.05	0.15	Extrusions
6061	0.4-0.8	0.7	0.15-0.4	0.15	0.13	0.25	0.15	0.05	0.15	Extrusions
7016	0.1	0.12	0.45-1.0	0.03	0.03	4.0-5.0	0.03	0.3	0.1	Bumpers
8079	0.05-0.3	0.7-1.3	0.05	- -	- -	0.1	- -	0.05	0.15	Household foil
Casting Alloys:										
A 380.1	7.5-9.5	1.0	3.0-4.0	0.5	0.1	2.9	- -	- -	0.5	Die castings
390.0	16-18	1.3	4.0-5.0	0.1	0.45-0.65	0.1	0.2	0.1	0.2	Engine block

* Data taken from the "Aluminum Recycling Casebook," the Aluminum Association, December, 1985.

† Alloys which are capable of utilizing large volumes of scrap recovered from consumer sources.

Figure 5-7: Generalized Diagram of Recycle Paths for Aluminum Scrap [a]
(Thousand MT of Recoverable Aluminum Content)

(a) Reported numbers are based on US consumption of aluminum for 1990; exports of aluminum products and scrap are not included.

aluminum old scrap in the nuclear industry in 1990 was about 0.6% of the annual old scrap utilization for aluminum. .

Scrap Consumption

In 1990, about 2.4 million MT of aluminum was recovered from new and old scrap. About 1.36 million MT of this secondary aluminum was recovered from post-consumer, or old scrap (Plunkert, 1992).

The consumers of aluminum scrap can be placed in one of the following general groupings: secondary aluminum producers, primary aluminum producers, non-integrated fabricators, foundries, and chemical producers:

- Secondary aluminum producers smelt or refine scrap and dross and in 1990 they consumed about 43% of all recycled aluminum old scrap. In general, the secondary producer does not use the most selective, higher purity scrap. Most scrap that reaches a secondary producer is a mixture of alloys and cannot be indiscriminately remelted to make finished products and must first be sampled for chemical analysis, moisture content, etc. The smelter will then blend the various grades of scrap to reach the desired chemical content. Most of the old scrap that is consumed by secondary smelters is used to make pre-casting alloys, with about 20% used to make extrusion billets, and a much smaller amount used in miscellaneous applications. Table 5-20 provides a summary of the secondary aluminum alloys that were produced by independent smelters in the US in 1990.

- Primary producers may either purchase scrap or may contract-fabricate returned scrap into mill products for their customers. In 1990 they consumed about 46% of all recycled old scrap. Most of the old scrap consumed by primary producers is in the form of old UBCs which are directly returned to primary producers for reprocessed into new can sheet. Some extrusion billets and pre-casting alloy are also processed.

- Non-integrated fabricators, foundries and chemical producers combined account for about 11% of all scrap consumption.

Table 5-21 provides a summary of US consumption of new and old scrap by class of consumer (Plunkert, 1993) while Figure 5-6 summarizes the aluminum production material flow for old scrap.

The major sources of aluminum old scrap are beverage cans which accounted for about 59% of all old scrap generated in 1990 (Plunkert, 1992). Most of the remaining scrap comes from automobiles, with a smaller component coming from building and construction (i.e., aluminum siding, etc.). Table 5-22 provides a more detailed breakdown of old scrap, new scrap and sweated pig consumption for each class of consumer.

Recycling and Life Cycles

The total scrap recycling rate for aluminum in 1990 (aluminum content of scrap consumed plus scrap exports as a percentage of adjusted total consumption) was about 41%. It is impossible to determine how much exported scrap

5-47

Table 5-20: Production of Secondary Aluminum Alloys by Independent Smelters in the US - 1990*

(Thousand MT)

Secondary Products	Production†
Die-cast alloys:	
- 13% Si, 360, etc. (0.6% Cu maximum)	60.9
- 380 and variations	273.4
Sand and permanent mold:	
- 95/5 Al-Si, 356, etc. (0.6% Cu maximum)	16.6
- No. 12 and variations	W
- No. 319 and variations	57.3
- No. 319 and variations	8.7
- F-132 alloy and variations	0.7
- Al-Mg alloys	2.6
- AL-Zn alloys	11.9
- Al-Si alloys (0.6% to 2% Cu)	1.8
- Al-Cu alloys (1.5% Si maximum)	1.2
- Al-Si-Cu-Ni alloys	1.5
- Other	
Wrought alloys: extrusion billets	125.6
Miscellaneous:	
- Steel deoxidation	4.9
- Pure (97.0% Al)	0.03
- Aluminum-base hardeners	1.5
- Other	34.4
Total	603.0
Less consumption of materials other than scrap:	
- Primary Aluminum	43.3
- Primary Silicon	29.1
- Other	3.3
Net metallic recovery from aluminum scrap and sweated pig consumed in the production of secondary aluminum ingot	527.2

* Data taken from the "Aluminum, Bauxite, and Alumina Annual Report, 1990," US Bureau of Mines.

† Aluminum production data is slightly different from consumption due to production losses and differences in reporting.

Table 5-21: US Consumption of New and Old Aluminum Scrap,* by Class

(Thousand MT)

Class	Old Scrap Consumption	New Scrap Consumption
Secondary smelters	582	360
Primary producers	631	454
Fabricators	88	158
Foundries	19	51
Chemical Producers	39	11
Total	1,359	1,034

*   Based on information reported to the US Bureau of Mines.

Table 5-22: US Consumption of Purchased New and Old Aluminum Scrap and Sweated Pig in 1990*
(Thousand MT)

Class of Consumer and Type of Scrap	Consumption	Change in Stocks
Secondary smelters:		
• Old scrap		
– Castings, sheets and clippings	333.5	+3.3
– Aluminum-copper radiators	11.5	0.0
– Aluminum cans	198.9	+5.6
– Other	44.6	+0.1
Total	588.5	+9.0
• New scrap	377.0	+4.6
• Sweated pig	16.5	-0.5
TOTAL	982.0	+13.1
Primary producers, foundries, fabricators and chemical plants:		
• Old scrap		
– Castings, sheets and clippings	169.2	+0.3
– Aluminum-copper radiators	38.3	0.0
– Aluminum cans	654.9	-17.3
Total	862.4	-17.0
• New scrap	699.6	-0.4
• Sweated pig	17.4	0.0
TOTAL	1,579	-17.4
All scrap consumed:		
• Old scrap		
– Castings, sheets and clippings	502.7	+3.5
– Aluminum-copper radiators	49.8	0.0
– Aluminum cans	853.8	-11.7
– Other	44.6	+0.1
Total	1,450.9	-8.0
• New scrap	1,076.6	+4.2
• Sweated pig	33.9	-0.4
GRAND TOTAL	2,561.4	-4.2

* Data taken from "Aluminum, Bauxite, and Alumina Annual Report - 1990," US Bureau of Mines; corresponds to gross weight consumption of aluminum scrap and includes imported scrap.

is old scrap, however, it can be estimated that the recycling rate for aluminum old scrap by itself in 1990 was about 22-26%.

Aluminum scrap has a high residual value, and thus, its recycling rate is linked to its availability and the technological ability to recover the aluminum from the form of scrap. There have not been any life cycle studies performed for the aluminum industry since the late 1970s. Due to recent advances in recycling technology, particularly with regard to UBCs, it is expected that the recycling rates for certain classes of aluminum products may be somewhat different today. A study done at Battelle Laboratories in 1972 estimated the following lifecycles for different sources of aluminum scrap: containers and packaging, 1 year; consumer durables and transportation, 10 years; building and construction, 35 years; machinery and equipment, 20 years; all others, 10 years (Battelle, 1972).

A 1979 study estimated life cycles for about 75 end uses for which aluminum shipment data is accumulated. The life cycles ranged from 3 months for metal cans to 60 years for electrical power transmission and distribution cables. The study also used estimated lifecycle, product weight and stock consumption data to estimate the input/output of aluminum recovery from old scrap. Table 5-23 is an estimated matrix of aluminum old scrap generation and recovery for 1979. From this table it is concluded that in 1979 about 23% of old scrap was actually recovered for recycling, about 44% could be added to the old scrap recycling stream, and the remaining 33% was classified as too difficult to recover for technological and economic reasons (Aluminum Association, 1985).

5.2.3.3 Factors Relevant to Cost Benefit Studies

Markets and Prices

Purchase prices for aluminum scrap, as quoted by the American Metal Market (AMM), have experienced significant fluctuations historically. Table 5-24 summarizes the year-end price ranges for selected types of aluminum scrap.

Energy Requirements

It has been estimated that the recycling of aluminum consumes about 5% of the energy required to produce aluminum metal from bauxite ore. It has been estimated that overall, mining, refining and reduction energy requirements for the production of aluminum range from 125 to 161 million Btu per MT of aluminum metal. In comparison, between 3 and 30 million Btu per MT of energy are estimated to be required to recover 1 MT of aluminum from aluminum-base scrap. Table 5-25 provides a summary of the energy requirements for each of the various stages required to produce aluminum metal.

Table 5-23: Estimates for Old Scrap Aluminum Generation and Recovery for 1979*

(Thousand MT Gross Weight)

| Source | Total Old Scrap Becoming Available | Difficult to Recover | Not Presently Recovered | | Actually Recovered |
			Possible Consumer Collection	Possible Other Channels	
Building and construction	141	32	59	64	27
Transportation	500	102	- -	170	227
Consumer durables	318	64	95	95	64
Electrical	91	36	- -	45	9
Machinery and equipment	182	55	- -	95	32
Containers and packaging	1,045	500	364	- -	182
Other	91	7	- -	67	17
TOTAL	2,409 (100%)	795 (33.0%)	518 (21.5%)	537 (22.3%)	558 (23.2%)

* Source - Estimate by the Aluminum Company of America, as reported in "Aluminum Recycling Casebook," the Aluminum Association, December 1985.

Table 5-24: Summary of Year End Prices for Selected Types of Aluminum Scrap*

Scrap Type	Price Range (¢/pound)
Mixed low copper aluminum chips	51¢ - 52¢
Old sheet and cast aluminum	42¢ - 44¢
Clean, dry aluminum turnings	45¢ - 47¢
UBCs	42¢ - 46¢
Secondary aluminum ingots	
- Alloy 380 (1% zinc content)	73¢ - 74.5¢
- Alloy 360 (0.6% copper content)	76¢ - 77¢
- Alloy 319	74¢ - 75.5¢

* Data taken from the American Metal Market.

Table 5-25: Summary of Energy Requirements to Produce Aluminum Metal*

	Energy Required (million Btu per MT)
Scrap:	
Total melting scrap to aluminum:	3 - 30
Mining and reduction to aluminum:	
• Bauxite: (mining and drying)	1.1 - 3.3
(shipping to US ports)	0.5 - 3.3
• Alumina: (steam)	22
(caustic soda)	15.4
(calcining)	9.9
(miscellaneous)	5.5
• Aluminum: (reduction of alumina)	48.5 - 68.3
(carbon)	14 - 19
(anode and cathode baking)	2.5 - 6.1
(holding furnace, casting and melting)	5.7 - 8.6
Total mining and reduction:	125 - 161

* Data is taken from "Mineral Facts and Problems, 1985" Chapter for Aluminum, US Department of the Interior.

5.2.3.4 Factors Relevant to Worker Exposure Scenarios

Standards Relating to Worker Health and Safety

CFR 29 Part 1910, Section 1000 provides limits for airborne contaminants for toxic and hazardous substances that may affect workers' safety. With respect to the processing of aluminum scrap, the applicable standards are that the time-weighted average (over eight hours) of an employee's airborne exposure to aluminum shall not exceed 15 mg/m^3 for total dust inhalation and 5 mg/m^3 for a respirable fraction.

5.3 Nuclear Metal Recycle Industry

5.3.1 US Nuclear Contaminated Metal Recycle Industry

5.3.1.1 Overview of Current Domestic Production and Use

Based on information that will be presented in this section, it has been estimated that a total of about 20,000 MT of potentially recyclable scrap metal (RSM) is generated each year in the US. The main producers of contaminated scrap are the nuclear industry, the Department of Energy (DOE) and the Department of Defense (DOD). Figure 5-8 provides an overview of the RSM material flow in the US. A brief summary of contaminated scrap production and disposition for each of the main producers is provided in the following paragraphs.

The nuclear industry consists mainly of commercial power plants, test and research reactors and industrial facilities. Based on a detailed analysis of both utility and commercial reuse and recycling practices, it is estimated that the nuclear industry as a whole generates about 5,000-6,000 MT of RSM per year. Of this amount, about 85% of the annual generation of RSM comes from commercial nuclear reactors. This corresponds to about 50 to 60 MT per reactor unit per year. In general, RSM is only decontaminated and/or recycled in the nuclear industry when there is an economic benefit to do so. As such, the RSM that is generally recycled is either clean (i.e., no measurable activity) or has relatively small amounts of surface contamination. As shown in Figure 5-8, there are several different ways in which RSM generated within the nuclear industry is processed and disposed of. Most of the material generated by nuclear utilities is purchased by commercial processors who employ various surface decontamination techniques to reduce the level of activity to acceptable levels and resell the material commercially as scrap (Loiselle, 1993). In addition there is a smaller component of as much as 500 MT per year of material that is surface decontaminated and reused within the industry (Graves, 1993). There is also a small amount of scrap, estimated to be less than 10% of the total RSM volume (less than 500 MT/yr), which is decontaminated for unrestricted release on-site by individual utilities. The amount of decontamination activity performed by utilities is estimated to be small, however, as only a small number of utilities have extensive decontamination expertise in-

Nuclear Industry

Consisting primarily of the following:

1. *Nuclear Utilities*
2. *NRC-licensed Test & Research Reactors*
3. *Fuel Cycle Nuclear Facilities*

Scrap Generated:

~4,000-5,000 MT/yr

- Carbon Steel — 60%
- Cu Alloys — 20%
  - Admiral Brass
  - 90/10 Cu/Ni
- SS / Inconel — 15%
- Al & Miscell. — 5%

Decontaminated for reuse (commercial processors):

<500 MT/yr

A small amount of material decontaminated & sent directly back to nuclear utilities for reuse. This consists mainly of scaffolding and, to a lesser extent, lead shielding blankets.

Decontaminated for unrestricted release (commercial processors):

~4,000-5,000 MT/yr processed by surface decontamination techniques:

- Carbon Steel — abrasive grit-blasting
- Cu Alloys — primarily chemical methods
  - Admiral Brass
  - 90/10 Cu/Ni
- SS / Inconel — chemical or electrochemical
- Al & Miscell. — chemical or electrochemical

85-90% of the material is sold commercially as metal scrap

The remaining 10-15% is buried at licensed LLW disposal sites at a cost of $116-$280 per cubic foot

Decontaminated for unrestricted release (in-house utility):

<500 MT/yr

A small number of utilities have in-house surface decontamination processing capabilities, however, it is estimated that the total amount of contaminated material processed by these utilities does not exceed 10% of the total amount of material sent to commercial processors (i.e., QUADREX, SEG, etc.).

Surveyed and Free Released for unrestricted use (in-house utility):

A small amount of uncontaminated material is sent offsite for unrestricted free-release by utilities. Most of this material is non-metallic waste (such as paper, plastic gloves, etc.). For metallic waste, this number is expected to be negligible compared to the amount sent to commercial processors.

Currently, a nuclear utility is allowed to free release material if a survey demonstrates that the material has no detectable activity above background levels.

Figure 5-8: Current Recyclable Scrap Metal Material Flow (Thousand Metric Tons)

**Department
of Energy**

*Consisting of the entire
DOE weapons complex*

*Decontaminated for restricted release
(commercial processors):*

SEG currently has a contract to
decontaminate by metal melting
about 2,000 MT of metal from
Fernould at a cost of $1/lb.

SEG is pursuing additional contract
agreements with DOE to decontaminate
contaminated scrap for restricted use
within DOE.

SEG is the only remaining finalist under
consideration for the DOE scrap metal
program (SMP) which, if awarded, will
call for melting about 60,000 MT of
contaminated scrap

Metal ingots reused in
nuclear applications
within DOE

Scrap Generated:

(1)

~15,000 MT/yr

[This number is
expected to increase to
as much as 90,000
MT/yr with increased
D&D activities within
DOE]

Stored Scrap (within DOE):

~1,500,000 MT of contaminated
recyclable scrap metal in storage in the
DOE complex

  - ≈80% at Nevada Test Site

  - ≈10% at Oak Ridge Reservation

(1) SEG expects to process about 7,500 MT of contaminated scrap metal (DOE and DOD) in its metal melt facility in 1993. The SEG melter
has a 20MT capacity, 7,200 kWt induction furnace with a rated capacity of about 5 MT/hr or ≈25,000 MT/yr.

**Figure 5-8: Current Recyclable Scrap Metal Material Flow (Continued)
(Thousand Metric Tons)**

**Department
of Defense**

*Consisting primarily of
the following:*

*1. Conventional
     weapons testing*
*2. Army and Navy Test
     Reactors*

Scrap Generated:

From conventional
weapons tests (mainly
metal targets containing
depleted Uranium
projectiles)

and

From occasional
decommissioning of
Army and Navy test
reactors

(1)

*Decontaminated for restricted release
(commercial processors):*

SEG currently has a basic ordering
agreement with DOD to melt
contaminated metal from weapons
testing sites for restricted reuse within
DOE. To date, about 4,500 MT of
material has been processed.

→ Metal ingots reused in
nuclear applications

Stored Scrap (within DOD):

Tens-of-thousands of MT of
contaminated recyclable scrap metal
are in storage at DOD test range sites.

Some of this material is currently
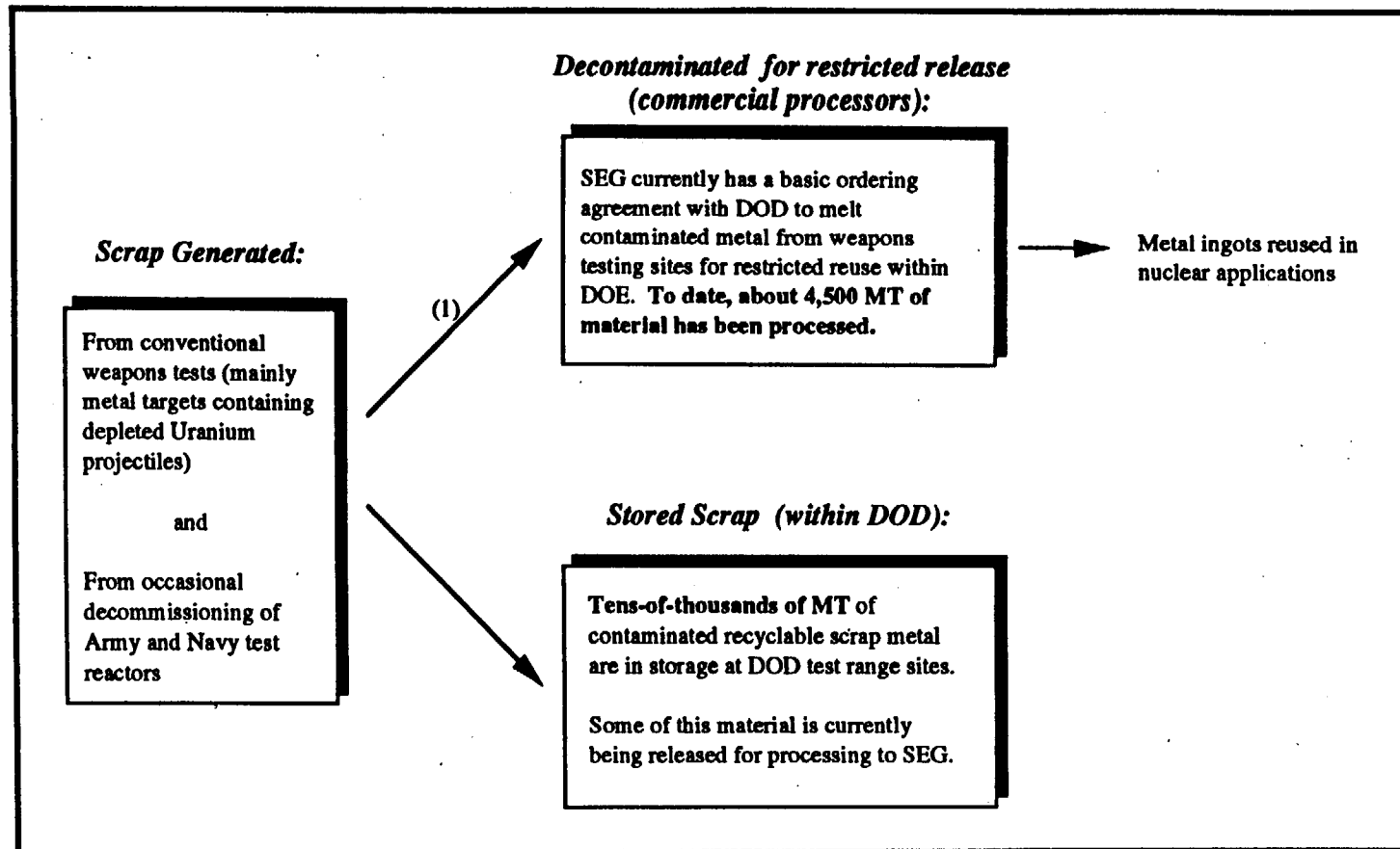being released for processing to SEG.

(1) SEG expects to process about 7,500 MT of contaminated scrap metal (DOE and DOD) in its metal melt facility in 1993. The SEG melter
     has a 20MT capacity, 7,200 kWt induction furnace with a rated capacity of about 5 MT/hr or ≈25,000 MT/yr.

**Figure 5-8: Current Recyclable Scrap Metal Material Flow (Continued)
(Thousand Metric Tons)**

house. There is also a component of material which contains undetectable levels of activity when surveyed which is freely released by utilities. With the exception of obsolete steam generators, there is no significant RSM storage in the nuclear industry. There are currently 12 obsolete steam generator units containing about 4,400 MT of RSM which are being stored on commercial nuclear reactor sites in the US and an additional 19 steam generator units which are scheduled for replacement in the next several years which would add an additional 6,900 MT of RSM (Loiselle, 1993).

DOE estimates that it generates about 15,000 MT of RSM each year with about 1.5 million MT of RSM in storage. It has been estimated that the annual generation of RSM may increase to as much as 90,000 MT per year with increased dismantling and decommissioning activities (Whitfield, 1991). There has been not been any continuous recycling of RSM in the DOE complex, however, a contract was recently awarded which calls for decontaminating, through metal melting, about 2,000 MT of RSM from the Fernould site for restricted release and reuse in nuclear applications within DOE (Carder, 1993).

Generation of RSM within DOD comes mainly from metal targets containing depleted Uranium projectiles resulting from conventional weapons testing activities and the occasional decommissioning of test reactors operated by the Army and Navy. The annual generation rate for RSM within DOD is not known, but is expected to be quite small. It is estimated that the total volume of RSM present at weapons testing sites is on the order of tens of thousands of MT (Carder, 1993). There has not been any continuous recycling of the RSM that has been generated within DOD, however, there was a contract awarded in 1992 which calls for decontaminating RSM from weapons testing sites and RSM generated from test reactors has been processed from time to time.

5.3.1.2 Treatment / Disposition of Recyclable Scrap Metal

There are four companies in the US which decontaminate RSM. Each of the four have the capability to remove surface contamination by a variety of techniques ranging from high pressure water, to abrasive, chemical and electrochemical techniques. Most of the surface decontamination activity involves material generated in the nuclear industry which is processed for unrestricted release according to the guidelines set forth in R.G. 1.86. QUADREX processes most·of this RSM (as much as 75% in 1992), with Chemical Waste Management (CWM-DSSI), ALARON and Scientific Ecology Group (SEG), processing the rest. If it is determined that the material cannot be economically decontaminated below release levels, it is volume reduced and packaged for burial as low level waste. Since all material coming in has undergone contamination characterization by the licensed generator, a cost/benefit decision is normally made on how to economically dispose of surface contaminated RSM, based on the cost of decontamination and low level waste disposal costs. Higher disposal costs tend to justify greater efforts at decontamination.

For processing of surface contaminated metal, each processing facility is required to have a state-issued license. The QUADREX facility has a Radioactive Material License issued by the State of Tennessee, and has limits written into its license, on the kinds and amounts of radioactive material which it is authorized to process. The total on-site inventory of radioactive materials can not exceed 100 curies, and there are additional limits for individual classes of isotopes. With regard to the unrestricted release of materials, the QUADREX license requires that the material only have surface contamination and that the surface contamination levels of the material meet the criteria set forth in R.G. 1.86. Material that has been processed requires a 100% survey of all surfaces to verify that it meets the release limits specified in the license. The SEG license is also issued in Tennessee and its conditions are very similar to those delineated above. DSSI and ALARON's licenses are expected to be similar.

Decontamination of RSM generated in DOE and DOD has only recently begun. All RSM that has been processed from DOE and DOD to date has been for restricted release for applications within the nuclear industry. An important reason for this is that most of the metal that is generated within DOE and DOD involves homogeneous contamination of the metal. There is no applicable standard that allows for free release of homogeneously contaminated metal; R.G. 1.86 only addresses surface contamination. Homogeneous decontamination is normally accomplished though metal melting, unless certain common alloying agents are contained in the metal. During metal melting, these common alloying agents (i.e., cobalt and nickel) will normally go right into the metal, while others that do not normally alloy will go into the slag or dust. Because of this phenomenon, surface decontamination is often employed before metal melt to remove certain alloying elements that may be present in the surface oxide layer of the metal. A more detailed discussion of the various decontamination techniques is provided in Chapter 4.

SEG has led commercial efforts to enter into contract agreements with DOE and DOD to process its RSM. SEG has the only licensed metal melt facility in the US and the facility has only recently begun full-scale operation. The melter is a 20 ton, 7,200 kWt induction furnace, with a rated capacity of about 5 tons per hour which translates into a capacity of about 25,000 MT per year. SEG expects to melt approximately 7,500 MT of material in the 1993 calendar year (Carder, 1993). The metal that is melted is beneficially reused, primarily within DOE (i.e., the production of shield blocks) with potential applications in the nuclear power industry (i.e., B25 burial boxes).

5.3.1.3 Contaminated Scrap Processing and Generation in the Nuclear Industry

As indicated in Section 5.3.1.1, about 5,000-6,000 MT of RSM is generated each year in the nuclear industry. This number has remained fairly constant in recent years, however, increased decommissioning activities in future years will have a significant impact on the generation of RSM. About 85% of this material is generated by the commercial nuclear power industry, with the remaining 15% coming from industrial nuclear facilities, and from the decommissioning of test and research reactors. This material can be either be disposed of as low level waste at a licensed disposal site (at a cost of $100-$280/ft^3), or sold commercially as scrap if it can be demonstrated to

be within acceptable release levels either by the utility or commercial processor. As such, RSM is only recycled from the nuclear industry when there is an economic benefit to do so. which means that the recycled material is generally either clean (i.e., no measurable activity) or has relatively small amounts of surface contamination. Table 5-26 provides a summary of the types of RSM that are generated in the nuclear industry and their approximate volumes, as well as the types of surface decontamination techniques that are typically employed (Graves, 1993).

The mechanism by which RSM material can be authorized for unrestricted release is different among commercial processors and nuclear utilities. As described in Section 5.3.1.2, the criteria for unrestricted released for non-utility licensees involve isotope specific activity limits which are similar to the levels prescribed in R.G. 1.86. For nuclear utilities, however, unrestricted release of scrap material is possible only if there are no detectable quantities of radioactivity. The NRC requires licensees that free release material to survey all material before it is released, and to verify that the material has undetectable levels of activity.

As summarized in Figure 5-8, there are several different ways in which RSM generated within the nuclear industry is processed and disposed:

- Most of the material generated by nuclear utilities is purchased by commercial processors who employ various surface decontamination techniques to reduce the level of activity to acceptable levels and resell the material commercially as scrap (Loiselle, 1993).

- A smaller amount of material (less than 500 MT per year) is decontaminated for reuse within the commercial nuclear power industry. There is about 3 million MT of scaffolding currently in use in the commercial nuclear power industry and about 700-850,000 pounds of scaffolding is decontaminated for reuse each year. To a much lesser extent, lead shielding blankets (with plastic covers) are also decontaminated and reused (Graves, 1993).

- There is also a small amount of scrap, estimated to be less than 10% of the total RSM volume (less than 500 MT/yr), which is decontaminated and released for unrestricted use by individual utilities. The amount of decontamination activity performed by utilities is estimated to be small as few utilities have extensive decontamination expertise in-house. Due to the restrictions for unrestricted release imposed on the nuclear utilities by the NRC (i.e., only non-detectable material can be released), the vast majority of utilities contract virtually all of their RSM for disposal to commercial processors (i.e., QUADREX, SEG, ALARON, etc.).

- There is also material which contains undetectable levels of activity when surveyed, and is free released as non-radiological waste by utilities. Much of this material is expected to be non-metallic dry active waste such as paper, plastic gloves, etc.

- With the exception of obsolete steam generators, there is no significant RSM storage in the nuclear industry. There are currently 12 obsolete steam generator units containing about 4,400 MT of RSM which are being stored on commercial nuclear reactor sites in the US. There are an additional 19 steam generator units which are scheduled for replacement in the next several years which would add an additional 6,900 MT of RSM (Loiselle, 1993). Obsolete steam generators are expected to have extremely high levels of surface and volume contamination which is not amenable to traditional surface decontamination methods to reduce activity levels to within acceptable limits for unrestricted release.

Table 5-26: Summary of Radioactive Scrap Metal Generation in the Nuclear Industry

Type of Scrap	Percent of Total Scrap Volume	Surface Decontamination Technique(s)
Carbon steel	60	Abrasive grit-blasting (using peanut shells, glass beads, silicon, or steel)

Copper alloys
  - Admiralty Brass
  - 90:10 Cu-Ni alloy .
	20	Primarily chemical methods (baths) to remove the oxide layer

Stainless steel and incanel	15	Chemical or electrochemical techniques
Aluminum and miscellaneous	5	Chemical or electrochemical techniques

As such, the nuclear utilities have not yet determined what the appropriate disposal method will be for obsolete steam generators.

5.3.1.4 Contaminated Scrap Processing and Generation in the DOE Weapons Complex

It has been estimated that the current RSM generation rate in the DOE Complex is about 15,000 MT per year (Whitfield, 1991). It should be noted that the DOE Complex includes weapons research activities performed as part of production operations (Weapons Complex), and as such, nearly all RSM generated in the production of weapons for DOD is generated as part of production operations in DOE. The RSM generation rate within DOE is expected to increase significantly to over 90,000 MT per year as soon as decontamination and decommissioning (D&D) projects begin (Whitfield, 1991).

In addition, a preliminary investigation has concluded that about 1.5 million MT of RSM is stored at various DOE sites, representing about 2% of the total scrap metal production in the US. About 80% of all existing DOE scrap metals were reported to be stored at the Nevada Test Site, with about 8% reportedly stored at various DOE storage yards in the Oak Ridge Reservation (Whitfield, 1991).

Data on the composition of scrap metals stored in the DOE Weapons Complex are quite scarce. Ongoing D&D projects generate much of the 15,000 MT per year discussed above and these projects have no plans for comprehensive RSM recycling. The production operations (Weapons Complex) at the DOE facilities reportedly generates significant volumes of low level and TRU contaminated metal scraps. No publicly available data, however, currently exist on this waste stream.

There has been not been any continuous recycling of RSM in the DOE complex; however, there have been some efforts in the last several years to process RSM generated within DOE, mainly for restricted release for use in nuclear applications. Currently, SEG has a contract with DOE for the processing of about 2,000 MT of RSM, associated with the decommissioning activities at the Fernould site, at a cost of about $1 per pound. SEG is also the only commercial processor under consideration for the DOE Scrap Metal Program (SMP) at Oak Ridge. If awarded, SMP calls for processing about 60,000 MT of RSM (Carder, 1993).

5.3.1.5 Contaminated Scrap Processing and Generation in DOD

Generation of RSM within DOD consists mainly of metal targets containing depleted Uranium projectiles used for conventional weapons testing activities. In addition, a small amount of RSM has been generated during the occasional decommissioning of test reactors operated by the Army and Navy. The annual generation rate for RSM

is not known, but is expected to be quite small. The vast majority of RSM is contained in various weapons testing sites.

There has not been any continuous recycling of RSM generated within DOD; however, SEG has entered into a basic ordering agreement with DOD to melt contaminated metal from weapons testing sites for restricted reuse within DOE, presumably to make lead shield blocks. To date, about 4,500 MT of RSM has been processed from a single weapons testing site. The agreement calls for processing material from a number of sites. It has been estimated that the total volume of RSM contained in weapons testing sites is on the order of tens of thousands of MT (Carder, 1993).

5.3.2 International Nuclear Contaminated Recycle Activity

The Commission of the European Communities (CEC) has an active program researching the decontamination of metal scrap from nuclear facilities. Industrial-scale processing of contaminated material (on the order of several thousand MT of material) has been performed in the Federal Republic of Germany, and to a lesser degree in France. Each country has a licensed facility dedicated to the melting of contaminated scrap metal.

In addition to this activity, research into possible melting processes, products, byproducts and radiological impact, as well as continuing work on other means of decontamination of equipment, materials, sites and buildings is being routinely done on a much smaller scale in several different countries.

The following sections summarize the activities of each country:

5.3.2.1 Germany

There has been a moderate amount of contaminated scrap recycling in Germany. More than 4,000 MT of metal has been decontaminated by melting at two different facilities since 1983. It also appears that there has been some material that has been surface decontaminated. Germany now has a licensed plant which is dedicated to the melting of contaminated metal generated by the nuclear industry, and the amount of contaminated scrap recycling is expected to continue to increase in the future. The focus of German decontamination efforts has been on restricted use in nuclear applications, and as such, it does not appear that there is any overlap with the commercial recycling industry for noncontaminated metals.

Initially, experiments into decontamination by metal melting were performed using an existing 20 MT coreless line-frequency-induction furnace at the Siempelkamp Foundry, Krefeld, Germany which was backfitted with a special charging device and a filter system (Sappok, 1987). Details of the melting work are described in a number

of papers by Dr. Manfred Sappok (Sappok, 1987; Sappok, 1989a; Sappok, 1991; and Sappok, 1992). These papers describe the initial test melter that was used to process about 1,500 MT of contaminated scrap. The metallic scrap had come partially from the decommissioning of the Gundremmingen nuclear power station, and also from backfitting and repairs of about seven operating nuclear power plants.

After the initial tests at the Siempelkamp Foundry were conducted, the decision was made to build a plant dedicated to the melting of contaminated material. Construction of a plant was initiated in early 1989 and the plant was commissioned in late 1989. A medium frequency coreless induction furnace with a weight of 3.2 MT was chosen. Its melting capacity is 2 MT/hr (Sappock, 1991). The plant has an offgas system specifically designed to accommodate the radioactive aerosols that are generated by the melting of contaminated metal. The facility is licensed by the German authorities and has limits on the input material (less than 200 Bq/g for alpha, beta and gamma emitters); the amount of fissile material introduced into the facility (100 Bq/g); the amount of fissile material in the product (1 g/100 kg of scrap); and the amount of fissile material in the slag (3 g/100 kg of slag). As of 1992, about 2,500 MT of material have been melted at this new facility. This material has included iron and steel, as well as aluminum, copper and brass (Sappok, 1992). The total quantities that have been melted are not stated in the article, but the information presented suggests that several MT of each metal have been melted in the new furnace.

Many of the research efforts that have been performed in Germany have been completed as part of the European Community's research and development program on the decommissioning of nuclear installations (1989-1993). The following paragraphs summarize the research efforts which have taken place:

- In 1985-86, a series of melting tests were performed at the Siempelkamp melter involving 175 MT of mixed steel scrap (activity 7 Bq/g) to produce shielding plates, 30 MT of carbon steel scrap (activity 5 Bq/g) to produce high quality castings, and 34 MT of austenitic steel scrap (activity 12 Bq/g) to produce bars for later recycling (Huber, 1987). These melting experiments concluded that the melt retained about 95% of the ^{60}Co which was the dominant radionuclide in the scrap treated, with smaller amounts of ^{110}Ag and ^{125}Sb found in some melts; the slag (1-1.5 wt% of the scrap input) contained the bulk of the Cesium activity, as well as smaller amounts of ^{54}Mn, ^{60}Co, ^{65}Zn, ^{144}Ce and ^{154}Eu; and the filter dust (0.1-0.4 wt% of scrap input) contained all types of radionuclides present in the scrap.

- A recent paper reports that over 4,000 MT of material has been removed to date from the Gundremmingen nuclear power station during its decommissioning (Eickelpasch, 1992). The decommissioning of the turbine hall has resulted in the decontamination and production of about 1,700 MT of metal (primarily steel) that can be used for unrestricted purposes, and about 1,500 MT of metal (primarily iron and steel) that was processed at the Siempelkamp foundry for production of waste containers to be returned for service in nuclear stations (Eikelpasch, 1983). In addition to the steel and iron, the paper reports the melting of 140 MT of admiralty brass (Sappok, 1989b). A recent IAEA report states that at the Gundremmingen site, about 365 MT of decontaminated concrete was used as a dam to block off a lake (IAEA, 1988). It is expected that more concrete will be used in this manner in the future. It was also reported that 1,100 MT of metal and 400 MT of concrete were released for unrestricted reuse.

- Another effort involves a large-scale investigation into alpha-emitter behavior under melting of alpha-contaminated steel from nuclear facilities, and to demonstrate the feasibility of the unrestricted release

of this material for reuse within legal limits (CEC, 1991a). The work is being performed cooperatively between Siemens AG, KWU Erlangen, and Siempelkamp Giesserie (SG). Following laboratory scale melts, large scale melts of about 100 MT of uranium and Pu-contaminated material from Siemens fuel fabrication and about 5 MT of Th-contaminated steel waste were scheduled to be carried out in early 1992. The specific contamination of the treated radwaste is estimated to be in the range of $\leq$ 200 Bq/g (alpha/beta) and the anticipated fission product inventory is estimated at about 200 g of U-235 and 1 g of Pu. The melts will be carried out in a 200 liter induction furnace.

- Another effort contracted to Siemens of Germany involved an investigation of recycling radioactive non-ferrous aluminum and copper by melting processes. This was undertaken to evaluate the behavior of the most relevant isotopes during melt decontamination in order to support guidelines for unrestricted release of material (CEC, 1991b). In this project 0.16 MT of radioactive surface contaminated aluminum scrap from different nuclear power plants was melted in a laboratory scale induction furnace (600 mm diameter crucible, 212 liter volume). After melting, a decontamination factor of 30 has been achieved for ^{60}Co and a factor of 3.5 for [110m]Ag. This project is ongoing through December, 1993.

- Another effort, performed by TUV-Bay, involved an evaluation of the radiological aspects of recycling contaminated concrete debris in order to support the development of limiting values for the restricted release of concrete with low level residual activity for selective non-dangerous utilization (i.e., noise barriers, earth fill, foundation material, etc.) (CEC, 1991c). This work focuses on simulating the washout of radioactivity by rainwater using a concrete test specimen from Gundremmingen Unit A. Twenty years worth of precipitation will be simulated over a 20 month span. Filtered concrete aggregates are collected from water that has seeped through the test specimen and measured spectroscopically. This work is ongoing through December, 1993.

- In another research effort in Germany, 67 200 liter drums of decontaminated scrap originating from the Obrigheim and Gundremmingen nuclear power plants were melted in an industrial furnace under an atmosphere to produce about 22 MT of ingots and 0.8 MT of slag. About 97% of the [60]Co (1 Bq/g in the scrap) remained in the billet and about 90% of the [137]Cs (0.5 Bq/g) went into the slag. The remainder went into the furnace liner and the cooler parts of the air duct system. The overall volume reduction including the slag was over 70% (Pflugrad, 1985).

- There have also been experiments involving the industrial-scale melting of tritium-contaminated steel from nuclear installations (CEC, 1991). This effort treated contaminated steel scrap from the Niederaichbach nuclear power plant and a tritium laboratory, in order to try to trap the tritium released during the melting process in a specially adapted exhaust system. The waste consisted of 13 tritium gas bottles and more than 1 MT of dismantled tubes, valves and housing materials. A total of about 0.6 MT of scrap with a specific activity of 100 Bq/g was melted.

5.3.2.2 France

A recent effort in France completed as part of the European Community's research and development program on the decommissioning of nuclear installations (1989-1993) involved the melting of ferritic steel arising from the dismantling of the G2/G3 reactors at Marcoule in a furnace installed at the dismantling site (CEC, 1991d). This effort involves the manufacture and installation of a 15 t electric arc heated melting furnace on the dismantling site of the G2/G3 graphite/gas reactors at Marcoule and to decontaminate through melting about 700 MT (out of a total of about 4,000 MT) of ferrous steel which will be continuously cast into 25 kg ingots. The steel scrap is expected to have contamination levels on the order of 20-40 Bq/cm^2. The following assumptions have been estimated for

the activity level and mass balance of steel scrap in the proposed furnace design: 250 Bq/g maximum basic activity; 30 Bq/g maximum during melting operations; total quantity of dust particles generated during the melting process (including graphite and refractory particles) is estimated at 10 kg per MT of steel; the slag is estimated at 10 kg per MT of cast steel (or 1%); the ventilation system is assumed to trap about 97.5% of particulate matter, the remaining particles will remain as fallout in the melting zone; and hot gases are cooled through a water jacket running from the furnace through an air cooling system before the HEPA filters.

Active testing of the melter with contaminated steel was expected to begin in early 1992. Further, in preparation for this work, preliminary melting of contaminated scrap was carried out in an industrial furnace, involving 3.8 MT of sections of piping from the G2/G3 reactors with a residual activity of 2.4 Bq/g. It was found that ^{60}Co accounted for about 95% of the activity in the contaminated scrap metal and its distribution in the processed dust/slag/castings was in the same proportions as the molten scrap. The remaining 5% of the activity contained ^{137}Cs, with about 90% of the ^{137}Cs found in the dust particles and 10% in the slag.

In addition to the work that is being done at Marcoule, several other research efforts have been cited in the literature, these include:

- It has been reported that about 30,000 Uranate transport drums, weighing about 750 MT, are decontaminated, remelted and released for unrestricted use each year in France (Chapius, 1986).

- Research has been performed at CEA/CEN Grenoble on the separation of stainless steel constituents using transport in the vapor phase (CEC, 1985).

- More than 1,500 MT of lead contaminated with <750 Bq/g was melted with a decontamination factor up to 1,000 (IAEA, 1988).

- Decontamination of tritiated metal generated in heavy water cooled/moderated reactors by melting has been practiced in France for many years. The primary purpose of this research has been tritium recovery and the melting process is only used for scrap with a tritium content of more than 37 TBq/t. The resulting ingot activity has been about 37 GBq/t (Guetat, 1986).

5.3.2.3 Japan

Japan has no practice in reuse or recycling of contaminated metals, but is conducting research in various technical areas related to such practices (Jupiter, 1992). The principle research areas at this time are:

- A demonstration program which involves the manufacture of concrete reinforcing bars from contaminated metals for use in construction at nuclear utilities. This research is being conducted by Nippon Steel Corporation and Mitsubishi Materials Corporation.

- A demonstration program to manufacture drum liners which will be used for shielding on nuclear waste drums. This research is being conducted by Mitsubishi Materials Corporation, Nippon Steel Corporation, and Kobe Steel, Ltd.

Articles published in the literature discuss other research that has been conducted. A 1987 article in Nuclear Technology reports research related to the melting of uranium contaminated metal (Uda, 1987). There has also been research reported which is related to the surface decontamination of contaminated metals with ice (Oguchi, 1989).

5.3.2.4 Netherlands

The Netherlands has no practice in recycling or reuse of contaminated metals, however, it has participated as part of the European Community's research and development program on the decommissioning of nuclear installations (1989-1993).

Recent research efforts in the Netherlands have involved investigating the potential for the recycling of activated/contaminated reinforcement metal in concrete (CEC, 1991e). This effort involved investigating whether or not contaminated steel could be recycled, as aggregate or reinforcement in concrete for new nuclear installations. Three different types of steel shapes were tested, fibres (long and short), granules and steel scrap. The contaminated steel was melted in order to gain activity reduction and a controllable product. For contaminated stainless steel and mild steel (mainly contaminated by ^{60}Co and ^{137}Cs), several different recipes for concrete were evaluated utilizing different combinations of contaminated metals and shapes. Each type of concrete was tested versus the workability and strength standards for concrete. It is not clear how much contaminated metal, if any, has been processed in this program.

5.3.2.5 United Kingdom

There has been no large-scale recycling of contaminated material in the UK, however, there has been some research and experimentation of metal melting technology. In the UK, solid insoluble radioactive waste with an activity of less than 0.4 Bq/g may be disposed of without authorization. This limit has been applied to a number of small operations in which a few MT of material have been recycled by smelting. In one application, about 2 MT of radioactive components were treated during 16 melts in 0.5 MT induction and 5 MT electric arc furnaces. The level of activity in the ingots were brought below 0.37 Bq/g by diluting up to 50 times with inactive scrap and by separation of radionuclides during melting (Gomer, 1985). The work showed that ^{60}Co remained in the ingot and ^{137}Cs went into the slag.

5.3.2.6 Switzerland

In Switzerland, laboratory studies have been performed to assess the behavior of ^{60}Co and ^{137}Cs during the melting of metallic scrap from nuclear power plants (Schenker, 1985). The results have shown that during melting, the percentages of ^{60}Co going into the casting were about 73% in an air atmosphere and about 94% if an argon cover was used. For ^{137}Cs, the results showed that 95% was trapped by the crucible if air was used and 69% with argon; most of the rest escaped as an aerosol.

5.3.2.7 Sweden

Sweden is in the process of establishing a decommissioning policy that can be used for planning and implementation of the coming Swedish decommissioning program. As part of this activity, the National Institute for Radiation Protection (NIRP) has encouraged a Swedish company, Studsvik Energiteknik AB, to set up a melter to develop and test melting of low level contaminated scrap material for reuse (Bergman, 1987). It is not known how much, if any, contaminated material has been processed to date in this program.

It has also been reported that about 1,500 MT of nuclear reactor heat exchanger tubes at 500 Bq/kg (gamma) have been melted in Sweden for unrestricted reuse since 1982 (Swedish National Institute for Radiation Protection, 1986). It was reported that the tubes were used for the production of ship propellers and similar items.

5.3.2.8 Italy

The Italian Regulatory Authority has criteria for exemption levels, as delineated in Appendix E, however, it does not appear that there has been any recycling of contaminated material from nuclear facilities. Since 1983, five small research reactors have been completely dismantled and one nuclear power plant has been authorized to perform activities aimed at safe storage conditions, including partial dismantling of equipment. Solid materials resulting from these decommissioning activities have been monitored for unrestricted release according to exemption guidelines (Benassai, 1988).

6. STANDARDS FOR RECYCLE AND REUSE IN THE UNITED STATES AND WORLDWIDE

6.1 Introduction

This section presents a summary of the standards that currently are used for restricted or unrestricted release of slightly contaminated material. The standards have been identified based on reviews of technical literature and contacts with regulatory and licensee personnel. The material is organized to address dose standards for members of the public (Sections 6.2.1 and 6.2.2) and then to address specific activity standards for specific material (Section 6.2.3).

The review of this information has shown that there is variability in the nature of dose and activity standards related to the disposition of material with very low levels of radioactive contamination. Some countries such as Finland have both dose and activity standards while other countries have only one or the other. In addition, some countries have neither but have still been able to take action on specific cases by applying more generic national or international standards. Table 6-1 summarizes the status relative to dose and activity standards in the countries covered by this review.

Table 6-1. Summary of Dose and Activity Standards Worldwide Related to Disposition of Material with Low Levels of Contamination

Country	Dose Standards	Activity Standards	Nature of Cases That Have Been Handled Under Existing Standards
Germany	None	Standards for beta and gamma contamination of iron and steel that have different activity levels depending on the subsequent use of the material	Have handled thousands of tons of material for both restricted and unrestricted recycle
United Kingdom	None	None	None identified
France	None	None specific to this situation, but some related ones have been used	Steel and concrete is recycled into the commercial sector with some restrictions. Lead is recycled only to the nuclear industry.
Italy	None	Specific standards for low level solid waste that does not require any treatment before release	None identified
Japan	None established in law although some recommendations have been made	None	Investigations and demonstrations are underway related to the manufacturing of concrete reinforcing bars and waste drum liners for use in nuclear facilities
Finland	Yes	Yes	None identified
Canada	Yes	No	None identified
Australia	Yes, for uranium ore contaminated material	No	None identified
United States	No	Regulatory Guide 1.86	Several thousands of tons per year is recycled without restrictions

6.2 Standards Applicable or Relevant to the Recycle or Reuse of Material

This section presents dose standards that are generic in nature (not specifically developed or recommended for use in material reuse or recycle situations) and specific in nature (ones that are specifically applicable to reuse or recycle situations).

6.2.1 General Dose Standards

ICRP

The ICRP has published principles for radiation protection in the area of waste disposal (ICRP, 1985). In this document, the ICRP concluded that annual effective doses on the order of 100 uSv/year could be disregarded and individual actions that result in effective doses on the order of 10 uSv/year could be exempted from regulatory practice. This reduction by a factor of ten allows for the situation where an individual may be subjected to exposure from several actions and still not receive a dose greater than the 100 uSv/year standard.

IAEA

The International Atomic Energy Agency (IAEA) published a report which provided recommendations for exempting material and practices from regulatory control. The report, IAEA Safety Series 89 (IAEA, 1988), calls for the application of two principles before a practice is exempted from basis safety standards. These principles are 1) individual risk must be sufficiently low so as to not warrant regulatory concern, and 2) radiation protection including the cost of regulatory control must be optimized.

6.2.2 Dose Standards Specific for Recycle or Reuse

This section presents dose standards or recommendations that are specific for such actions or practices as the recycle or reuse of material from nuclear facilities that have very low levels of radioactive contamination.

Japan

While the Government of Japan has not proposed any standards, the Japanese Radiation Council in a 1987 report suggested a criterion for exemption of material from low level waste disposal. The criterion was an individual dose of 10 uSv/yr (1 mrem/yr). This dose level is low enough that members of the public will not be exposed to

radiation levels that exceed the 1 mSv/yr (100 mrem/yr) dose limit for the public, even considering multiple sources (Oshino, 1988; Yamamoto, 1989).

Canada

The Atomic Energy Control Board (AECB) is the Canadian federal agency with responsibility for nuclear regulation. The AECB uses 0.05 mSv/year (50 uSv/year) as a *de minimis* dose of radiation for individuals as a result of disposal of slightly contaminated materials. Actions are approved on the basis of this standard, but on a case-by-case basis provided that analysis shows that the radiological impact will be localized and the potential for exposure of large populations is small. In addition, the case-by-case approval is often granted as a result of the AECB working in conjunction with provincial regulatory authorities whose regulatory area may be impacted by the exemptions (Jack, 1988; AECB, 1989)

Italy

ENEA/DISP is the Italian regulatory authority that addresses disposition of very slightly contaminated material. The Advisory Committee for Radiological Protection, a consultive body of the ENEA/DISP, has approved the use of an individual dose equivalent of 10 uSv/year as the dose level below which further efforts in the optimization of dose reduction is not necessary. This dose standard is used in the development of activity standards for the release of very slightly contaminated material (Benassai, 1988).

Australia

Australia's "Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores, 1987" has a provision that allows regulatory authorities to grant exemptions from some or all of the radiation protection requirements if they are satisfied that no employee is likely to receive an effective dose in excess of 5 uSv/year and no member of the public is likely to receive an effective dose in excess of 1 uSv/year.

Finland

The Finnish Center for Radiation and Nuclear Safety (STUK) has issued a YVL guide for the exemption of nuclear waste from regulatory control (STUK, 1992). This standard allows exemption from regulatory control if the expected radiation exposure to the maximally exposed member of the public or worker at unlicensed facilities is less than 0.01 mSv/year (10 uSv/yr) and the collective dose is less than 1 man-Sv per year.

6.2.3 Activity Standards

Commission of the European Communities (CEC)

A working party under the Group of Experts was formed on the initiative of the CEC and pursuant to Article 31 of the Euratom Treaty. The working party examined the establishment of both dose limits (individual and collective) and clearance levels (release limits). The working party decided in favor of clearance limits because of practical problems associated with dose standards. The clearance limits that were recommended (CEC, 1988) were:

1) **for beta/gamma radiation;**   a limit of 1 Bq per gram averaged over a maximum mass of 1000 kg and the additional requirement that no single item exceed 10 Bq per gram,

for non-fixed contamination, a limit of 0.4 Bq per gram on accessible surfaces averaged over 300 cm^2 or over the relevant surface if it is less than 300 cm^2; for fixed contamination a limit of 1 Bq per gram.

2) **for alpha radiation;**   a limit of 0.04 Bq per gram measured over any area of 300 cm^2 of any part of the surface.

Germany

Germany has a metal recycling program in place and there are standards that guide this program. There are standards which have been recommended by the German Radiation Protection Agency to the German Government for unrestricted release and two versions of controlled recycling (R. Neider, 1992). These are:

The unrestricted release standards for steel and iron are overall activity of less than 0.1 Bq/gram and surface contamination of less than 0.5 Bq/cm^2 for beta-gamma emitters. Each item has to comply with the standard and the surface contamination may be averaged over areas of 100 cm^2. In addition, there should be no detectable alpha contamination.

The release standard for steel and iron that is to be melted is an overall activity of less than 1 Bq/gram, surface contamination of less than 0.5 Bq/cm2 for beta-gamma emitters, and some certification that the released material is actually going into a furnace with other clean scrap.

The controlled recycling standard for iron and steel allows for the controlled melting of steel or iron which has activity greater than 1 Bq/gram or has a geometry too complicated to measure. This type of material can be melted under licensed conditions, but the material produced by this method of melting must be less than 1 Bq/gram in any case and may be released for unrestricted use only if the specific activity is less than 0.1 Bq/gram.

For all of these cases, alpha contamination is excluded. Standards for alpha contaminated material are being prepared. Similar standards for contaminated aluminum and copper are also in preparation.

Germany also has a standard for the release of scrap that has surface contamination only as a result of uranium mining and milling operations. This standard allows for the recycle of material that has surface contamination levels of less than 0.5 Bq/cm^2 as long as all the parts are destroyed so that they can not be reused and are then melted.

France

The French legislation for the disposition of material with very low levels of contamination is based largely on the Euratom Directive for basic radiation safety standards. This standard states that non-naturally occurring substances with an activity concentration of 100 Bq/g or less are exempt from the reporting and authorization requirements. While the standard was not prepared with disposal or recycling in mind, it has been used by the French as the basis for the disposal and recycling of small quantities of waste (Charles, 1992).

Italy

Radioactive wastes which decay to radioactive concentrations on the order of some hundreds of Bq/gram in time periods ranging from a few decades to a few centuries are categorized as second category waste by the Italian Directorate for Nuclear Safety and Radiation Protection in technical guide No. 26 (ENEA, 1988). This guide identifies dry solid waste which does not exceed specific radionuclide concentrations as being waste which can be disposed without any preventive conditioning. The radionuclide concentration units for solid dry waste are presented in Table 6-2.

Table 6-2. Radionuclide Concentration Limits for Disposal of Dry Solid Waste with Conditioning According to Italian ENEA Technical Guide No. 26

Radionuclide	Concentration Limit
Radionuclide with half life less than 5 years	18.5 K Bq/g (500 nCi/g)
Radionuclide with half life greater than 5 years	370 Bq/g (10 nCi/g)
Cs-137 and Sr-90	740 Bq/g (20 nCi/g)
Co-60	18.5 K Bq/g (500 nCi/g)

Finland

In addition to the dose limit identified previously, the Finnish regulatory authority has specific activity limits for material to be exempted from regulatory control (STUK, 1992). These limits are:

Total activity concentration: beta or gamma activity shall not exceed 1 Bq/gram or alpha activity shall not exceed 0.1 Bq/gram. The activity can be averaged over 1000 kg of waste. In addition, no single item weighing less than 100 kg may contain more than 100 Bq of beta or gamma activity or 10 Bq of alpha activity.

Surface Contamination: beta or gamma surface contamination shall not exceed 4 kBq/m^2 (0.4 Bq/cm^2) or alpha activity shall not exceed 400 Bq/m^2 (0.04 Bq/cm^2). The measurements are to be averaged over an area of less than 0.1 m^2.

Japan

According to a paper by Yamamoto (Yamamoto, 1989) the Japanese laws which regulate the utilization of atomic energy and radiation, the Reactor Law and the RI Law, do not explicitly present or refer to criteria for the reuse of sites, facilities, materials, or waste. Some reuse is authorized when facilities are at the end of their life and owners present decommissioning plans which present proposed decontamination levels and disposition of material to the regulatory authorities. If the plans contain reuse or recycle proposals and if they are approved, then de facto criteria are established on a case-by-case basis.

Apart from the laws which are the basis for regulation of nuclear activities, the Japanese Nuclear Safety Commission, an advisory organ to the Japanese government, issued a report on regulatory policy for low level waste which indicated the possibility of restricted reuse of extremely low level radioactive wastes.

United States

The United States Nuclear Regulatory Commission has been using Regulatory Guide 1.86 "Termination of Operating Licenses for Nuclear Reactors," as a statement of methods and procedures considered to be acceptable by the NRC staff for reactor license termination. The guidance also identifies criteria that can be used to determine if the equipment and structures can be released for unrestricted use. Table I of this guide was not based on any individual dose objective, but rather on variations in background and lower limits of detection for survey instruments.

7. DOSE ASSESSMENT STUDIES FOR RECYCLE AND REUSE OF CONTAMINATED MATERIALS

7.1 Background

Over the last twenty years various assessments have been made, in the United States and in Europe, to quantify the potential for radiation exposure to workers and the general public from recycle of contaminated metals and other materials. The general approach for these assessments is based on formulation and evaluation of scenarios that describe hypothetical situations in which workers or members of the public might be exposed to radioactivity in recycled metals. Iron and steel have received the most attention (O'Donnel 1978, Oztunali 1984, CEC 1988, Neider 1988, Charles 1992, Deckert 1992, IAEA 1992, Kennedy 1993) followed by copper (O'Donnel 1978, Oztunali 1984, Deckert 1992, Garbay 1992) and aluminum (Bergman 1985, Deckert 1992, Garbay 1992, Kennedy 1993). A few studies have considered recycle of concrete (Charles 1992, Kennedy 1993) and glass (Oztunali 1984).

The principle difference in approach between studies done in the United States and Europe lies in their treatment of radiation dose limits. The general practice in Europe has been to compare the estimated radiation doses resulting from mandated "exemption level" concentrations of radioactivity with established *de minimis* doses. Exemption level concentrations are those below which unrestricted release of contaminated material is deemed to have insignificant potential for adverse impacts on public health. Concentrations below exemption levels are therefore not subject to regulation. Similarly, *de minimis* doses are those below which no significant potential for adverse impacts on public health is thought to exist and no regulatory control is required. The most commonly evaluated exemption level is 1 Bq/g and the most commonly used *de minimis* dose is 10 uSv/year (CEC 1988). Most studies conducted in the United States estimate the normalized radiation doses from unit concentrations of radioactivity without reference to either exempt levels or *de minimis* dose limits.

There is no generally accepted standard method for conducting dose assessments of recycled materials. However, in many respects all of the key dose assessment studies are similar to one another in technical approach. This is largely due to the fact that these studies are not entirely independent. For example, many make reference to earlier work done in the United States for the U. S. Nuclear Regulatory Commission and rely on it for calculational methods and parameter values (O'Donnel 1978). In spite of these similarities in technical approach, the radiation doses estimated by these studies vary widely. This is a natural consequence of the way in which exposure scenarios are developed.

The key studies assessing recycle of contaminated materials depend on the evaluation of hypothetical exposure scenarios. Scenario-based assessments are widely used to estimate the potential risks of exposure to radioactivity

and other materials. It is characteristic of scenario-based assessments that they are very sensitive to the assumptions incorporated in their exposure scenarios. The way in which these scenarios are developed has a direct influence on how the results of each assessment are interpreted. Therefore, it is important to understand the nature and limitations of scenario-based assessments in general.

Each scenario consists of a description of the hypothetical circumstances surrounding potential human exposures. These circumstances typically include 1) the magnitude, duration, and other characteristics of the radioactive release (e.g. the source term), 2) the estimated concentrations of radioactivity resulting from transport through the environment and 3) assumptions about various elements of human behavior that control exposure to those concentrations of radioactivity. Each of these three elements is distinctly different in nature and suffers from different limitations.

The models that are used to estimate transport of radioactivity are, in part, mathematical descriptions of the physical and chemical processes in the environment. Typical transport pathways include atmospheric dispersion of airborne effluents, dispersion of liquid effluents in groundwater, and movement of radioactivity through the food chain. Recycle studies may also include models of physical transport through industrial processes that can bring radioactivity into contact with people. These processes can include scrap decontamination and handling, smelting, manufacturing, and distribution of products containing recycled materials. The transport models tend to be similar from one scenario-based study to another. The mathematical treatment of these processes tends to follow conventional approaches developed for a broad range of other assessments. In addition, because the transport models are intended to estimate concentrations of radioactivity, they are subject to confirmation by direct measurements of those concentrations. For these and other related reasons, comparison of transport models among different assessment studies often focuses on the selection of values for specific parameters in the analysis rather than on the fundamental models used.

Assumptions about human behavior surrounding potential exposures are treated quite differently from the transport models. Once the concentrations of radioactivity in the environment, the workplace, or consumer products have been estimated, evaluation of potential exposure depends on assumed patterns of behavior that vary widely depending on the purpose of the study. Often the available range of circumstances is so wide as to allow for any level of exposure from negligible to extreme. One common approach is to attempt description of a "bounding" scenario in which potential exposure is maximized even though the combination of circumstances described may be unusual or improbable. Another approach is to develop a suite of "typical" scenarios that address a range of possible exposures. In either case, the results of the analysis often depend more on the choice of scenario than on the numerical value of any particular parameter in the calculation. Therefore, comparisons between studies should focus on the stated purpose for the analysis and the scenario descriptions used.

As a consequence of this dependence on the specific scenario and parameters used, comparison of dose estimates across studies requires some care. Accounting for differences between studies can be complicated and often requires more detailed information than is available in the open literature. Some studies are sufficiently well documented, with all equations and parameter values provided, so that individual dose calculations can be checked (O'Donnel 1978, Kennedy 1992, Charles 1993). In these cases, differences between scenarios can be evaluated and the consequences of different assumptions can be evaluated. Other publications provide only summary results and brief descriptions of scenarios that are not a sufficient basis for detailed comparison with other studies. With this caution in mind, the following sections review eleven key dose assessment studies for recycle of radioactively contaminated materials.

7.2 Synopsis of Selected Dose Assessment Studies

There is a broad literature on the use of scenario-based dose assessments for a variety of applications such as operation of nuclear facilities, evaluation of accidental releases of radiation, and radioactive waste treatment and disposal. This review focuses on only the much smaller number of studies that specifically address the recycle or reuse of radioactively contaminated materials. Eleven key dose assessment studies are described here, numbered from 1 to 11. These numbers are also used to refer to each study in the tables that follow. Each synopsis provides a reference citation, describes the purpose of the study, the recycled materials it treats, and the radionuclides considered. A tabular summary of these studies is presented in Table 7-1.

1.   Bergman, C., R. Boge, "Collective Doses from Recycling of Contaminated Scrap Metal", National Institute of Radiation Protection, Sweden, 1985.

The purpose of this document was to present a summary of collective doses calculated during an actual recycling event that occurred in Sweden. The event was at Ringhals 1, a 750 MW(e) BWR-reactor, where the aluminum-brass alloy turbine condenser tubes were replaced by titanium tubes in 1981. At the time of replacement, the condenser had been in service for seven years. Thirty five tons of metal were ultimately recycled. Twenty one radionuclides were considered. This document only calculated doses for occupational and public exposure during the recycling process. The recycled metal was to be used in manufacturing ships propellers. Only inhalation and direct external exposures were considered.

This document went through the recycling process step-by-step and stated what type of exposure would be critical and what the collective dose (occupational and public) would be in each step. A contamination level of approximately 100 Bq/kg, based on the dose-rate measurements taken at the time of replacement. The results are not given in a table format, only in the text.

Table 7-1. Summary of Selected Dose Assessment Studies

Doc No.	Material Recycled	Reuse (Y/N)	Radionuclides Considered	Scenarios Calculated
1	Fe	N	21 listed	Occupational: handling, transport, smelting (collective doses)
2	Fe	Y	α, β, γ	Occupational: scrap piles, repair Public: furniture, cars, slag in concrete Doses: individual and collective
3	Fe, concrete	N	45 listed	Occupational: smelting, transportation, fabrication Public: smelting, furniture, cars, residential construction Doses: individual and collective
4	Fe, Al, Cu	Y	non-α (Co-60) α (Pu-239)	Occupational: scrap yard, transport, foundry and production Public: products > 1000 kg, and < 1000 kg
5	Al, Cu	N	9 listed	Occupational: storage, refining, manufacture Public: use of products, copper IUD, slag
6	Fe	Y	56 listed	Public: landfill, incineration, recycle and reuse
7	None	Y (land)	over 200 (including decay chains)	Occupational: building renovation Public: building (office) occupancy, drinking water, residential use of land No doses calculated
8	Fe, Al, and concrete	Y	16 listed	Occupational: 7 scenarios Public: 6 scenarios Doses: individual and collective
9	Fe	Y	α, β, γ	Public - waste disposal
10	Fe, Cu	N	27 listed	Occupational: scrap yard, smelter Public: smelters, slag, frying pans, plumbing
11	Fe, Cu, glass steel	N	85 listed	Occupational: smelter workers (individual dose) Public: "All persons in a recycle pathway" (collective dose)

2. RADIATION PROTECTION No. 43, "Radiological Protection for the Recycling of Materials from the Dismantling of Nuclear Installations", Commission of European Communities, Luxembourg, November, 1988.

The purpose of this document is to recommend criteria for the recycle and reuse of materials from nuclear facilities. This document specifically discussed steel, but it can also be applied to copper and aluminum. The radionuclides that are addressed are those which are known to be present in nuclear installations. The scenarios discussed were occupational and public. The occupational scenarios involved the workers in the recycle process, while the public scenarios involved the consumer use of products or exposure to large structures with contaminated recycled material (i.e., reinforcements in buildings, or slag in concrete).

These scenarios were chosen based on conservative assumptions which allow for the normal uses of steel products. The calculations were made based on the following clearance levels: 1 Bq/g for 1000 kg or 0.4 Bq/cm^2 over 300 cm^2 for β/γ and 0.04 Bq/cm^2 over 300 cm^2 for α-contaminated materials.

The values of the parameters used were based on realistic data from the steel industry, as much as possible. When the values varied greatly, the value that resulted in the highest dose was chosen. While the models used were very simplified, the scenarios are described in detail (e.g., the time it takes for a pump repair and the average distance to the worker). The equations used, as well as the parameter values were listed. Both individual and collective doses were calculated for the scenarios. The collective dose of the ultimate disposal of the recycled steel and aluminum was also calculated. This document gives doses for each scenario and for each radionuclide as well as total doses.

3. Charles, D. and G. M. Smith, Waste Management Study for Large Volumes of Very Low Level Waste from Decommissioning of Nuclear Installations, Intera Information Technologies, December 1992.

The purpose of this study was to examine the available waste management options for very low level radioactive waste from decommissioning of nuclear power stations in the CEC. The report characterized the waste streams of interest; described the waste management options of unrestricted release, recycling/reuse, and disposal as radioactive waste. The materials considered for recycling were steel and concrete. Individual and collective doses were calculated for both occupational and product consumer scenarios. Occupational scenarios included smelter, manufacturing, and transportation workers. Product consumer scenarios included users of steel furniture and automobiles made from recycled steel and residents of buildings constructed from recycled concrete and steel products. To evaluate the effects of radioactive decay, sets of scenarios in each category were calculated for materials used at different times following reactor shut down.

Results were presented for only those radionuclides giving the largest proportion of the dose for each scenario. However, all equations were provided and data were given for all radionuclides. The results for the unreported

nuclides could, in principle, be calculated using the information provided. The equations and parameter values used were derived largely from CEC Report No. 43 (CEC 1988).

4. Deckert, A., R. Graf, and R. Görtz, "Radiation Exposure to the General Public from Reclaimed Metals Out of Nuclear Facilities", Proceedings of the Symposium on Waste Management, Vol. 2, pp 1809-1814, Tucson, AZ, March 1-5, 1992.

The purpose of this article was to present a systematic method for studying the radiological consequences of releasing slightly activated or contaminated metallic material from a control zone. The following materials were addressed in this article: ferrous metals, aluminum, and copper from operation and decommissioning of LWR nuclear power facilities. Radiation dose from individual radionuclides was not addressed. Two mixtures of radionuclides were discussed, non α-contaminated (primarily Co-60) and α-contaminated (primarily Pu-239). Two exposed groups were discussed; process workers and product users. The process workers scenarios involved the actual process of recycling the material. Two different sets of scenarios involved the public; exposure to steel products under 1000 kg and products over 1000 kg.

Deckert used a stochastic (Monte Carlo) approach to estimate concentrations of radioactivity in recycled steel. The equations and basic parameters for exposure to these concentrations were deterministic (non-stochastic) and were taken from O'Donnell, 1978. Exemption limits of 0.5 Bq/100 cm^2 and 1.0 Bq/g were assumed. The resulting doses are compared to the *de minimis* dose of 10 uSv/yr. The published documentation is insufficient to duplicate the analysis. However, Deckert discussed the different factors which should be considered when developing a scenario, such as inhalation of foundry exhaust by the workers and the public and ingestion from normal wear of a frying pan.

Rather than providing a comprehensive list of radiation dose for many radionuclides, this article only gives examples of exposures calculated. For example, it lists the average individual dose from 200 simulations of exposure to recycled steel containing no alpha emitters as 13 uSv/yr and the 99th percentile dose as 69 uSv/yr.

5. Garbay, H., A.M. Chapuis, "Radiological Impact of Very Slightly Radioactive Copper and Aluminum Recovered from Dismantled Nuclear Installations", Commission of European Communities, Luxembourg, 1992.

The purpose of this document was to define the derived applicable limits by studying the radiological impact of copper and aluminum recycling in terms of individual risk. This document addressed copper and aluminum recovered from French PWR's. The radionuclides considered were: Fe-55, Co-60, Ni-63, Sr-90, Ru-106. Ag-110m, Cs-137, Pu-238, and Pu-239. The authors calculate exposures to workers, consumers, and the general public. Several commercial products using recycled copper were addressed. The dose limiting scenario was use

of an interuterine device (IUD) made out of recycled copper. The exposures calculated are for external and ingestion for the consumer and inhalation during the recycling process for the general public. Occupational exposures included inhalation and external.

This document calculated concentrations limits resulting in a dose of 10 uSv/yr. The scenarios are briefly described but no details on the modeling approach are given. The equations and parameter values for different generic exposure scenarios are also given. The distribution of radionuclides during copper and aluminum scrap smelting (maximum fractions) are given. The doses are given in several different forms (tables).

6.   IAEA, "Exemption from Regulatory Control -- Recommended Unconditionally Exempt Levels for Radionuclides in Solid Materials", Draft Working Document, November 1992.

The purpose of this document was to recommend a set of exempt levels which apply to solid materials regardless of how they are to be used after control has been relinquished. The approach taken in this study is unique. Rather than conducting new assessment calculations, this document summarizes other studies on the recycle and reuse of slightly contaminated metals. It lists contamination levels resulting in an individual dose level of 10 uSv/a calculated in the dose-limiting scenario from each of the other studies, but does not describe the calculational methods or the details of the scenarios. Rather, it uses the results for comparative purposes against a set of exempt levels calculated on the radiological characteristics of each radionuclide. The studies summarized in this report address contamination levels for landfill disposal, incineration, recycle of steel, and direct reuse of tools and buildings. The following references, which dealt with recycle and reuse, were summarized:

A.   International Atomic Energy Agency, Draft Working Document on the Application of Exemption Principles to Recycle of Materials from Nuclear Facilities, IAEA, Vienna, 1991. (Reference No. 8 listed above)

B.   Commission of the European Communities, Radiological Protection Criteria for the Recycling of Materials from the Dismantling of Nuclear Installations, Radiation Protection No. 43, CEC, Luxembourg, 1988. (Reference No. 2 listed above)

C.   Elert, M., Wiborgh, M. and Bengtsson, A., "Basis for Criteria for Exemption of Decommissioning Waste", Kemakta Ar 91-26, Kemakta Konsult AB, Stockholm, Sweden, 1992.

D.   Garbay, H., Chapuis, A.M., Cahuzac, O., Guetat, P., Haristoy, D., Renaud, P., "Impact Radiologique, dû au cuivre et à l'aluminium très faiblement radioactifs provenant du démantèlement 'installations nucléaires, EUR 13160FR, Commission of the European Communities, Luxembourg, 1991. (An earlier version of reference No. 5 listed above)

F.   Guetat, P., Chapuis, A., Renaud, P., "Disposal of Very Low Radioactive Wastes (VLRW) in Conventional Industry. The Case of Landfill for Municipal or Industrial Refuse", Joint Int. Symp. on Environmental Consequences of Hazardous Waste Disposal, Stockholm, Sweden, May 27-31, 1991.

7.   Kennedy, W.E., and D.L. Strenge, "Residual Radioactive Contamination from Decommissioning: Volume I, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent", September, 1992, NUREG/CR-5512.

The purpose of this report was to provide generic and site-specific dose conversion factors for residual radioactivity. No recycled materials were considered, only the reuse of land and structures was discussed. However, this study is key to the assessment of recycling for three reasons. First, the issue of residual radioactivity from decommissioning is closely related to the recycling of materials from decommissioning. Second, it presents a comprehensively documented methodological approach which can be broadly applied to recycling assessments. Finally, this study provides a basis for comparing disposal of decommissioning waste as the primary waste management alternative to recycling.

Over 200 radionuclides, including decay chains, were addressed in four scenarios: Residual contamination in buildings, building renovation activities and normal building occupancy; and unrestricted use of land, drinking water (only) scenario and residential use of land. The major exposure pathways, direct exposure, inhalation, and ingestion, were included for each scenario.

The authors of this report took a generic modeling approach to estimating doses from residual radioactivity in buildings and land. Input parameters for each exposure pathway and scenario were selected to provide a prudently conservative estimate of the potential radiation dose to a member of a given population group. That is, the derived estimates may be overestimates, but they would not be "worst case". Each scenario was described in detail and listed the equations used. Volume 1 does not give actual dosimetric results for the given scenarios. Volume 2 of this report will contain the user's guide for the computer code under development for the implementation of the models in Volume 1. Volume 3 will contain a sensitivity analysis of parameters used in the modeling, and a comparison with previously used guidance such as NRC Regulatory Guide 1.86.

8.   Kennedy, W.L., F.R. O'Donnell, and G. Linsley, "Exemption Principles Applied to the Recycle and Reuse to Materials of Nuclear Facilities" (Draft), IAEA, publication anticipated in 1993.

The purpose of this study was to "illustrate a methodology that can be used by national Authorities to develop practical radiological criteria for exemption by recycle and reuse." Recycled materials addressed in this study were aluminum, steel, and concrete from pressurized water reactors. Equipment reuse scenarios addressed tools and

and buildings with surface contamination. Bulk or volume contamination typical of activation products was not treated. Sixteen radionuclides were considered: (Cl-36, Ca-41, Mn-54, Fe-55, Co-60, Ni-63, Zn-65, Sr-90, Nb-94, Ic-99, Cs-137, Eu-152, U-238, Pu-239, Pu-241, Am-241). Occupational doses were calculated for external, inhalation, and ingestion. Public doses were calculated for external and ingestion pathways. The occupational exposures were calculated only during the recycling process, and the public doses were estimated only for use of the resulting products. The public doses from recycle processes such as exhaust from the foundry were not calculated. Individual and collective doses were calculated for both occupational and public.

The calculations were based on an assumed activity of 1 Bq/g of each nuclide for specific activity and 1 Bq/cm^2 for surface activity. This document provides a detailed description of the type of workers exposed and the different exposures to the public. It also listed the assumptions used in calculating the doses (i.e., the amount initially recycled, the consumer products useful lifetime, and the amount that is again recycled). This document also provides the individual and collective doses for each radionuclide, each scenario (public and occupational), each recycle step, and each exposure mode (inhalation, ingestion, external). It also states the limiting exposure mode for each radionuclide (i.e., recycle step, scenario, exposure pathway).

9.   Neider, R. et al, "Criteria and Conditions for the Unrestricted Release of Materials from Decommissioned Nuclear Facilities", Proceedings of an International Conference on Radiation Protection in Nuclear Energy, Sidney, Australia, April 18-22, 1988.

This article states the criteria for unrestricted release of materials from decommissioned nuclear facilities. The materials addressed by Neider are steel and iron. The radioactive contaminants considered were classed as α-, β-, or γ-emitters but no specific radionuclides were given. No specific scenarios were discussed. Neider described several different environmental transport pathways associated with waste disposal. Neider used a stochastic model for physical transport through industrial processes that can transfer contamination to consumer products.

The following exemption limits were assumed: 1 Bq/g for 1000 kg or 0.4 Bq/cm^2 over 300 cm^2 for β/γ and 0.04 Bq/cm^2 over 300 cm^2 for α-contaminated materials. There was no documentation provided for the dose calculations.

10.   O'Donnell, F.R. et al, "Potential Radiation Dose to Man from Recycle of Metals Reclaimed from a Decommissioned Nuclear Power Plant", U.S. Nuclear Regulatory Commission, NUREG/CR-0134, 1978.

This is among the earliest comprehensive dose assessments for recycled metals and has provided the technical approach for several subsequent studies. The purpose of this report was to present a "generic methodology for estimating radiation doses to individuals and to population groups from recycling radioactively contaminated scrap metals that may be reclaimed from decommissioned nuclear power plants, or any other nuclear facility." O'Donnell demonstrated the methodology by using a hypothetical problem. This report addressed the recycle of ferrous metals and copper. Twenty seven radionuclides which are characteristic of nuclear power plant inventories were considered for both occupational and public scenarios. The occupational scenarios included doses received by the workers during the recycle process. The public scenarios included the use of products by consumers as well as the dose to the members of the public who live near smelters or are exposed to slag. The exposure pathways considered are external and internal (ingestion and inhalation).

The scenarios were based on detailed time and distance descriptions of industrial processes. In the frying pan manufacture scenario, for example, the number of hours spent by a foundry worker at specified distances from the pans at each step of fabrication were included in the analysis. The exemption limit of 10 pCi/g was assumed, to be consistent with Reg. Guide 1.86. The key equations and parameter values are given for the generic scenarios. The dose calculations were done using a modified version of the CONDOS code. Dose conversion factors were given for each of the 27 radionuclides.

11.   Oztunali, O.I., and G.W. Roles, "De Minimis Waste Impacts Analysis Methodology", US NRC, NUREG/CR-3585, February, 1984.

This report presents a methodology for calculating exposures to individuals and populations resulting from the recycle of the metal or glass component of *de minimis* waste. The materials addressed were glass, copper, stainless steel, and bulk iron. Eighty five radionuclides were considered and both occupational and public scenarios were addressed. In this report, the term "public" refers to "all persons in the recycle pathway (population)". This report referred to O'Donnell 1978 for the description of the scenarios. The exemption limits assumed were: 10 pCi/g for most, 2 pCi/g for Sr-90, and 0.2 pCi/g for Pu-239, Am-241. The equations used and the parameter values for the highest dose scenario are given.

7.3   Discussion

Even though the potential for radiation exposure from recycled materials has been evaluated by several independent investigators over the last twenty years, there is no comprehensive study that addresses all the materials of concern or all the major categories of relevant exposure scenarios in a consistent manner. Taken

together, the eleven key studies reviewed here represent a broad coverage of the materials and scenarios of interest. However, because of the inherent difficulties in comparing differently formulated scenarios, the results of these studies can not easily be combined to give a comprehensive evaluation.

Evaluation of the literature on dose assessment studies depends strongly on the scenarios included in these assessments. Typical scenarios address some combination of individual and collective doses to workers, product consumers, and members of the general public. These scenarios fall into two general groups, depending on whether they emphasize the industrial process of recycling contaminated materials or the end use of products containing radioactivity. Tables 7-2 through 7-4 indicate which types of scenarios have been evaluated in the eleven selected studies for iron and steel, copper, and aluminum. It is clear from these tables that no single assessment has covered all the scenarios of interest in a consistent way for even these four metals. Even when taken together, the available assessments do not allow easy comparison of potential radiation doses for different metals and different radionuclides.

The draft working document of the IAEA (reference 6), for example, includes comparisons of results from several assessment studies. These include studies of incineration, landfill disposal, and recycling for as many as 56 radionuclides. The differences among these studies were such that no directly comparable scenarios were identified. Rather, the approach was to compare the limiting, or highest dose, scenario from each study for each radionuclide. Even this approach required careful reading of the assessments under comparison so that some available assessment studies were set aside because of obvious biases in the results. Even with these precautions, dose estimates range over several orders of magnitude. Explaining the differences in these results requires a detailed examination of scenario assumptions and parameter values, making it very difficult to formulate general conclusions.

Occupational scenarios are typically formulated to evaluate potential radiation doses to workers at various steps in the recycling process. Each investigator made different assumptions about the recycling industry and identified different occupational activities to characterize the potential radiation hazards to workers. In those studies where collective dose to workers is evaluated, there was no general agreement in estimates of the affected population of workers.

Consumer exposure scenarios vary even more widely than those for workers. They range from evaluation of close physical contact by individuals with recycled metals to remote and incidental exposure by populations of consumers. One end of this spectrum is exemplified by scenarios such as the hypothetical copper interuterine device (IUD) considered in Garbay, 1992. The other extreme includes such scenarios as exposure to

contaminated steel used in reinforcing bars for roadways and bridges considered in Charles, 1992.

Doses to the general public are usually based on projected exposure to effluent releases associated with the recycle process or product use. Scenarios addressing these doses typically include exposure to atmospheric effluents from industrial processes, such as smelting, or external radiation from transportation and distribution of contaminated consumer products. Disposal of industrial by-products, such as smelter slag, also provide the basis for estimates of dose to the public. Public dose scenarios show the greatest apparent consistency among the different studies reviewed. However, attempts to compare dose estimates among studies have shown that even fairly conventional scenarios, such as landfill disposal, show a very wide range of estimated doses.

Table 7-2. Assessment Scenarios Treated in Reviewed Studies: Iron and Steel

	Product Use			Recycle Process		
	Inhalation	Ingestion	External	Inhalation	Ingestion	External
Individual Dose						
Worker				2,3,4,6, 8,10,11	2,3,4,6, 8,10,11	2,3,4,6, 8,10,11
Consumer	4,10,11	4,8,10,11	2,3,4,8,10,11			
Public	4,10,11	4,10,11	2,3,4,8,10,11	3,6,9	3,6,9	3,6,9
Collective Dose						
Worker				2,8	2,8	2,8
Consumer		8	2,8			
Public			2,8			

Table 7-3. Assessment Scenarios Treated in Reviewed Studies: Aluminum

	Product Use			Recycle Process		
	Inhalation	Ingestion	External	Inhalation	Ingestion	External
Individual Dose						
Worker				4,8	4,8	4,8
Consumer	4	4,8	4,8			
Public	4	4	4,8			
Collective Dose						
Worker				1,5,8	8	1,5,8
Consumer		5,8	5,8			
Public		5	5,8	1,5		1

Table 7-4. Assessment Scenarios Treated in Reviewed Studies: Copper

	Product Use			Recycle Process		
	Inhalation	Ingestion	External	Inhalation	Ingestion	External
Individual Dose						
Worker				1,10,11	1,10,11	1,10,11
Consumer	1,10,11	1,10,11	1,10,11			
Public	1,10,11	1,10,11	1,10,11			
Collective Dose						
Worker				5		5
Consumer		5	5			
Public		5	5	5		

The wide range of numerical results from different assessments is illustrated by the data presented in Table 7-5 adapted from IAEA, 1992. The values in the table are nuclide-specific exemption levels, corresponding to an individual dose of 10 uSv/year, derived from the limiting scenarios of several different studies. Calculated exemption levels for Co-60 are a useful example since Co-60 is often a major dose contributor in consumer product scenarios. The values in Table F-5 for Co-60 range from 1×10^{-2} to 5×10^{0} Bq/g. In comparison, the nearest corresponding value from Charles, 1992 would suggest an exemption level for Co-60 of 2×10^{2} Bq/g.

While there are difficulties in comparing the numerical results from these studies, there are some broad generalizations that can be drawn from them. For example, the estimated doses from the use of contaminated metals in consumer items are dominated by external exposure from gamma-emitting radionuclides. Further, the gamma emitters of greatest concern are those that are the most difficult to separate from metals during the smelting process. Thus, radionuclides such as Co-60, Cs-134, and Cs-137 generally result in the highest estimated doses for these scenarios. While most scenarios for doses to workers show similar large contributions from external exposure to gamma-emitters, inhalation dose to workers can be significant under some sets of assumptions. This is particularly true if alpha-emitting transuranics are assumed to be present during the smelting and manufacturing processes. In contrast, an entirely separate set of radionuclides and exposure pathways tends to dominate dose estimates for landfill disposal of these contaminated materials. Ingestion dose generally becomes the most important pathway and the radionuclides of interest include the long-lived, environmentally mobile radionuclides such as Ni-63.

The scenarios that lead to the largest projected collective doses are those where contaminated material is widely distributed in the population. Consumer use of recycled steel, for example, generally results in higher dose estimates than transportation of products containing recycled steel.

Finally, there appears to be a consensus among all the studies reviewed here regarding the significance of the potential radiation doses from recycling contaminated materials. All estimates of radiation doses to the public are quite small and are arguably insignificant as a public health concern. In particular, the proposed European exemption levels of 1 Bq/g seem to ensure annual doses of less than 10 uSv/yr. None of these studies indicate the potential for large radiation doses that would present a significant threat to the public health.

Table 7-5. Summary of Results of Studies on Exemption Levels for Recycle[a,b]
$(Bq \cdot g)^{-1}$

Radionuclides	Steel			Aluminum		Copper	Concrete			All Materials
	IAEA (1991a)[d]	CEC (1988)[e]	Elert et al. (1991)	IAEA (1991a)[d]	Garbay et al. (1991)[c]	Garbay et al. (1991)[c]	IAEA (1991a)[d]	Haristoy (?)	Elert et al. (1991)	Guetat (1991)
H-3									5×10^{-2}	7×10^{4}
C-14									3×10^{1}	2×10^{3}
Na-22										1×10^{0}
Na-24										5×10^{-1}
P-32										7×10^{2}
S-35										2×10^{4}
Cl-36									1×10^{-3}	2×10^{2}
Ca-45									7×10^{2}	7×10^{3}
Cr-51										7×10^{1}
Mn-54	4×10^{-1}	1×10^{1}	8×10^{-1}	1×10^{0}	2×10^{1}	6×10^{2}	1×10^{0}		4×10^{-2}	2×10^{0}
Fe-55	1×10^{4}	2×10^{5}	2×10^{2}	1×10^{3}	2×10^{5}	2×10^{5}	2×10^{5}		2×10^{1}	2×10^{4}
Fe-59										2×10^{0}
Co-57										2×10^{1}
Co-58			3×10^{0}						3×10^{-2}	2×10^{0}
Co-60	1×10^{-1}	2×10^{0}	1×10^{-1}	3×10^{-1}	5×10^{0}	2×10^{1}	3×10^{-1}	1×10^{0}	1×10^{-2}	1×10^{0}
Ni-63	2×10^{4}	2×10^{5}	2×10^{3}	4×10^{4}	1×10^{6}	4×10^{4}	1×10^{5}		1×10^{2}	1×10^{4}
Zn-65	6×10^{-1}		2×10^{0}	2×10^{0}	3×10^{1}	8×10^{1}	2×10^{0}		5×10^{-2}	3×10^{0}
Sr-89										1×10^{3}
Sr-90	5×10^{1}	4×10^{1}	2×10^{0}	2×10^{2}	8×10^{2}	3×10^{2}	3×10^{2}	2×10^{2}	2×10^{-3}	2×10^{2}
Y-90							5×10^{-1}			3×10^{2}
Nb-94	2×10^{-1}		2×10^{-1}	5×10^{-1}	7×10^{0}	2×10^{1}			2×10^{-2}	1×10^{0}
Tc-99m										2×10^{1}
Tc-99	7×10^{3}		3×10^{1}	2×10^{4}			5×10^{4}		5×10^{-2}	6×10^{3}
Ru-106			1×10^{0}		4×10^{1}	6×10^{1}			2×10^{-2}	1×10^{1}

Table 7-5. Summary of Results of Studies on Exemption Levels for Recycle[a,b] (Continued)
$(Bq \cdot g)^{-1}$

Radionuclides	Steel			Aluminum		Copper	Concrete			All Materials
	IAEA (1991a)[d]	CEC (1988)[e]	Elert et al. (1991)	IAEA (1991a)[d]	Garbay et al. (1991)[c]	Garbay et al. (1991)[c]	IAEA (1991a)[d]	Haristoy (?)	Elert et al. (1991)	Guetat (1991)
Ag-110m					6×10^0	2×10^1				1×10^0
Cd-109										3×10^2
In-111										6×10^0
I-123										2×10^1
I-125										2×10^2
I-129									8×10^{-4}	2×10^2
I-131										6×10^0
Sb-124										1×10^0
Cs-134		5×10^0	2×10^0		1×10^1	3×10^1			2×10^{-2}	1×10^0
Cs-137	5×10^{-1}	8×10^0	5×10^0	1×10^0	2×10^1	9×10^1	1×10^0	6×10^0	3×10^{-2}	3×10^0
Ce-144			2×10^0						1×10^1	3×10^1
Pm-147			2×10^2						1×10^2	1×10^3
Eu-152	4×10^{-1}			1×10^0	1×10^1	5×10^1	1×10^0	3×10^0	3×10^{-2}	2×10^0
Eu-192										3×10^0
Au-198										6×10^0
Tl-201										3×10^1
Pb-210										7×10^{-1}
Po-210										5×10^0
Th-228										1×10^{-1}
Th-230										1×10^{-1}
Th-232										1×10^{-2}
Ra-226								2×10^0		1×10^0
Ra-228										2×10^0
U-234					5×10^1	7×10^0				3×10^{-1}

Table 7-5. Summary of Results of Studies on Exemption Levels for Recycle[a,b] (Continued)

$(Bq \cdot g)^{-1}$

Radionuclides	Steel			Aluminum		Copper	Concrete			All Materials
	IAEA (1991a)[d]	CEC (1988)[e]	Elert et al. (1991)	IAEA (1991a)[d]	Garbay et al. (1991)[c]	Garbay et al. (1991)[c]	IAEA (1991a)[d]	Haristoy (?)	Elert et al. (1991)	Guetat (1991)
U-235					3×10^1	7×10^0				3×10^{-1}
U-238	1×10^0			5×10^0	5×10^1	7×10^0	3×10^0	1×10^0		4×10^{-1}
Np-237					1×10^1	2×10^0				1×10^{-1}
Pu-239	3×10^{-1}	1×10^{-1}	1×10^{-2}	1×10^0	1×10^1	2×10^0	1×10^0		9×10^{-3}	1×10^{-1}
Pu-240			1×10^{-2}					3×10^{-1}	9×10^{-3}	1×10^{-1}
Pu-241	1×10^1		6×10^{-1}	7×10^1			5×10^1		5×10^{-1}	4×10^0
Am-241	3×10^{-1}	1×10^{-1}	1×10^{-2}	1×10^0	1×10^1	2×10^0	1×10^0	3×10^{-1}	9×10^{-3}	1×10^{-1}
Cm-244		2×10^{-1}	2×10^{-2}		2×10^1	3×10^0			2×10^{-2}	2×10^{-1}

a. The values listed from each of the studies are the most limiting from the various exposure scenarios considered.

b. Except where noted, values are based on an individual dose level of 10uSv.a.

c. Based on an individual dose criterion of 10uSv.a for exposures of large groups of people and 50uSv.a for relatively small groups of individuals.

d. Base case results - dilution and partitioning not included.

e. Includes a dilution factor of 10.

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