ANALYSIS OF DISPOSITION ALTERNATIVES FOR RADIOACTIVELY CONTAMINATED SCRAP METAL[1]

L.A. Nieves, S.Y. Chen, E.J. Kohout, B. Nabelssi, R.W. Tilbrook, and S.E. Wilson
Argonne National Laboratory, Argonne, IL 60439 USA

Millions of tonnes of slightly radioactive, scrap iron and steel, stainless steel, and copper are likely to become available as nuclear and other facilities and equipment are withdrawn from service. Disposition of this material is an international policy issue under consideration currently. The major alternatives for managing this material are to either develop a regulatory process for decontamination and recycling that will safeguard human health or to dispose of the scrap and replace the metal stocks. To evaluate the alternatives, we estimate quantities of scrap arising from nuclear power plant decommissioning, evaluate potential price impacts of recycling on regional markets, and assess the health and environmental impacts of the management alternatives. We conclude that decontaminating and recycling the scrap is the superior alternative.

INTRODUCTION

Slightly contaminated radioactive scrap metal (RSM) arises from operations of nuclear power plants, nuclear fuel cycle facilities, weapons production facilities, research and development reactors, high-energy accelerators, industrial sterilizer plants, industrial radiography equipment, medical facilities and equipment, and petroleum and phosphate rock extraction equipment. Millions of metric tons (t) of scrap iron and steel, stainless steel, and copper are likely to become available in the future as these facilities are withdrawn from service. We develop scrap inventory estimates for one of the largest sources, nuclear power plants.

The major alternatives for managing RSM are to either (1) develop a regulatory process for decontamination and recycling that will safeguard human health or (2) dispose of the RSM and replace the metal stocks. To date, relatively small quantities of RSM from various facilities have been recycled for public use, but thousands of tons have been recycled within the nuclear industry (Menon and Teunckens 1994; Hertzler et al. 1993). The magnitude of the potentially available supply, as well as the very low level of radioactivity in a major portion of it, warrant consideration of a broad range of end uses for this material. The International Atomic Energy Agency has recently published an interim report (IAEA 1996) proposing radioactive contamination levels below which materials may be released from regulatory control for recycling or other purposes. The Commission of the European Communities has also issued a draft proposal (1995).

The Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) has been examining the issues through a Task Group on Recycling and Reuse and Release of Materials from Nuclear Facilities (NEA/OECD draft 1995). The study discussed below (see Nieves et al. 1995 for detail) was conducted in conjunction

[1]Work supported by U.S. Department of Energy, Assistant Secretary for Environmental Management, under contract W-31-109-Eng-38.

with the NEA/OECD effort. It evaluates the management alternatives for radioactive steel scrap within the context of the system of radiological protection recommended by the International Commission on Radiological Protection (ICRP) (1991). Impacts of recycling are compared to those associated with disposing of and replacing the metal. We conclude that recycling is justified as a practice, that radiation protection can be optimized through implementation of a tiered system of release criteria, and that individual dose can be controlled to acceptable levels.

International guidelines

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

Given these guidelines, this study evaluates the health risks, environmental impacts, and socioeconomic issues associated with the RSM management alternatives. Both radiological and nonradiological risks to human health are assessed, but the treatment of radiological risks is more detailed. The assessment of health risks focuses on the public, including industrial workers. Illustrative examples are presented for iron and steel scrap because it constitutes a major portion of the potential RSM volume. The values that are specific to steel in this report would need further investigation before the findings could be applied to the recycling of nonferrous metals. Environmental impacts are discussed in terms of the nature and relative magnitude of effects on environmental quality and resources. Scrap metal market impacts related to recycling RSM are identified, and their implications for implementation of recycling are discussed.

Policy alternatives

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

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

Disposal of the total potential international RSM inventory of 2.5×10^7 t from power plants, fuel cycle and weapons facilities as LLW would require disposal capacity of approximately 4.6×10^6 m^3. This would result in about $9 billion in disposal charges alone at recent U.S.A. rates for surface disposal. Although new LLW disposal facilities are anticipated to become available, disposal costs are likely to continue to increase, and access to disposal sites is likely to be limited on the basis of the geographic location of the waste generator. In a number of European countries, LLW disposal facilities currently are available or under construction, but in general new facilities will be required to accommodate wastes generated during nuclear facility decommissioning (Nuclear Energy Agency 1991). There are major political constraints on availability of disposal capacity because siting and operation of LLW disposal facilities is a significant issue in several countries.

Public acceptability of recycling

The public may see the choice between recycling or disposing of RSM as an issue of having a metal supply that is clean versus having one that is radioactive, although the issue is not actually that clear-cut. Iron and steel, for instance, generally contain small amounts of naturally occurring radioactive materials that originate with the ore deposits or with the coal used in coke production. In addition to naturally occurring activity, there are several other sources of radioactivity in iron and steel. For example, traces of Co-60 from measuring devices used in smelting are commonly found in steel, and reports are increasingly frequent of the discovery of metal that has been accidentally contaminated by the inclusion of sealed radiation sources with melted scrap or for which the activity source is unknown.

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

POTENTIAL SCRAP INVENTORY FROM WORLD NUCLEAR POWER PLANTS

Quantities of potential scrap metal are estimated for the world listing of nuclear power plants (American Nuclear Society 1992; Nuclear Engineering International 1991, 1992, 1993). These estimates have been calculated with spreadsheet techniques and application of algorithms to estimate quantities of metal from each source on the basis of plant size and reactor type.[2] Only power plants listed as under construction or completed by 1993 are included. Reactors of less than 100 MWe are excluded.

Most of the metal scrap resulting from dismantlement of nuclear power plants is not radioactive. The nonradioactive scrap includes metal that normally has not been exposed to radioactivity during reactor operations (e.g., in a turbine hall). However, just by being on a nuclear power station site, all metal may be exposed to activity from a blowdown, from off-gassing, or even from neutrons passing through the biological shielding. Therefore, all metal on the site will be required to be treated as suspect and surveyed before being moved off the site.

Amounts of nuclear power plant scrap metal potentially available annually are estimated by geographic region, with scrap metal from each plant assumed to become available 50 years after start-up. This timing reflects a 40-year plant lifetime plus 10 years for achieving cold shutdown, draining and securing systems, and regulatory permitting.

To provide perspective on the total metal inventory, Table 1 provides estimates of total metal masses for major regions of the world and also worldwide totals. These estimates indicate the mass of each metal type that would be available in the suspect radioactive or removable surface contamination categories from all reactors if each reactor were dismantled 50 years after its start-up date. Additional quantities of metal that is activated or has fixed contamination will also be available. If these smaller quantities are stored to permit radioactive decay, they may also be recyclable, substantially reducing the quantity and, therefore, the cost of material requiring burial as radioactive waste.

The values shown in Table 1 as totals for regions and the world represent the available stock of metal from 2010 to 2043. Thus, about 7.6×10^6 t of decontaminatable iron and steel scrap will be available from nuclear power plants worldwide, with major portions of that total originating in North America and Europe. Copper scrap mass is less than a third of that for iron and steel.

METAL MARKET IMPACTS

Increasing scrap metal supply by recycling RSM is expected to create downward pressure on scrap prices. International scrap prices depend on several other factors, such as local demand, logistics (transportation costs, timing, etc.), quality (grade), exchange rates, and trade barriers (if applicable). The high transportation cost associated with scrap tends to segment markets geographically.

The magnitude of the effect of recycling RSM will depend on the relative size of the RSM flow and on the demand situation. Comparison of the potential annual RSM flow with measures of metal demand in regional markets indicates that RSM is likely to constitute a very small portion of scrap imports or of annual variation in scrap consumption in these markets. As a result, price impacts are expected to be small. The one exception is copper because the RSM quantities are sufficient to depress prices

---

[2] See Nieves and Tilbrook (1996) for a discussion of the methods used to estimate metal quantities.

TABLE 1 Estimated Power Plant Scrap Metal Mass by Activity Category, 50 Years after Plant Start-Up, by Metal Type and by Region (1000 tonnes)

Region/Activity	Copper	Iron and Steel	Stainless Steel
North America			
Suspect radioactive	669	1,025	6
Surface contaminated — removable	11	902	136
Total[a]	680	1,927	142
Europe			
Suspect radioactive	771	1,693	4
Surface-contaminated — removable	13	1,128	183
Total[a]	784	2,821	184
Former Soviet Union			
Suspect radioactive	324	1,285	0
Surface-contaminated — removable	5	480	173
Total[a]	329	1,765	173
Asia			
Suspect radioactive	335	478	2
Surface-contaminated — removable	5	456	61
Total[a]	340	934	63
Rest of World			
Suspect radioactive	40	82	1
Surface-contaminated — removable	1	55	12
Total[a]	41	137	13
World Total[a]			
Suspect radioactive	2,139	4,563	13
Surface-contaminated — removable	35	3,021	565
Total[a]	2,174	7,584	578

[a] Totals may not add because of rounding.

somewhat in some regional markets.

Market impact analysis

Demand for scrap from obsolete products depends on the difference between total market demand for scrap and the quantity of industrial scrap available. In weak markets, industrial scrap may meet all of the demand for scrap, with the demand for obsolete scrap falling to nothing. In high demand periods, the demand for obsolete scrap increases as the supply of industrial scrap is consumed (Institute of Scrap Iron and Steel 1984). Thus, business fluctuations in the metals industry are greatly magnified for those handling obsolete scrap. This section provides some measures of possible impacts and some perspective on the scrap market.

Table 2 presents the projected average annual international RSM releases from nuclear power plants over the period 2010 to 2043. These estimates are added to the quantities of RSM from enrichment facilities. The resulting sum is doubled to account for RSM from weapons plants and other sources as well, producing the annual scrap flow estimates that follow. Iron and steel scrap together, at 5×10^5 t/yr, dominates the other metals and will provide by far the greatest quantity of scrap. Copper is second, at 1×10^5 t/yr, and stainless steel is third, at 4×10^4 t/yr.

Increasing the supply of scrap by recycling RSM is expected to create downward pressure on scrap prices, assuming the quantity of scrap metal demanded remains constant. But demand rarely remains constant, and the global economy has shown increasing volatility in recent years. In addition, other market forces can overwhelm this downward price pressure, either positively or negatively, especially if the quantity of new scrap metal coming on the market is a small fraction of the existing market flows. For example, increased demand due to an improving global economy or increased secondary refining capacity could provide much greater upward price pressure. A worsening global economic climate would probably affect scrap prices more than would a small increase in supply. Another point to consider is that even if the increase in scrap supply leads to lower scrap metal prices, this situation will likely have a beneficial effect for scrap metal consumers.

TABLE 2 Projected Average Annual Releases of Suspect and Surface-Contaminated — Removable Categories of Radioactive Scrap Metal from Power Plants Worldwide, 2010-2043

	Releases (1000 t)		
Region	Copper	Iron and Steel	Stainless Steel
North America	20.6	58.4	4.3
Europe	23.8	85.5	5.6
Former Soviet Union	10.0	53.5	5.2
Asia	10.3	28.3	1.9
Rest of World	1.2	4.2	.4
Total[a]	65.9	229.8	17.5

[a] Totals may not add due to rounding.

One measure used to assess the potential impacts of recycling RSM is ratio of the average quantity of RSM available from power plant decommissioning annually to the 1989 international scrap metal imports (British Geological Survey 1991), because, to some extent, this new source of scrap metal will be competing with imports. If the potential RSM is a small fraction of imports, then minimal impacts can be expected, however, the measure may be misleading for producing/exporting regions which may have small imports and large ratios. These ratios, presented in Table 3, were computed for five

TABLE 3 Projected Average Annual Flows of Radioactive Scrap Metal from Power Plants as Percentages of 1989 International Scrap Metal Imports

Region	Copper (%)	Iron and Steel (%)
North America	10	2
Europe	2	-[a]
Former Soviet Union	32	5
Asia	3	-[a]
Rest of World	2	2
Total	4	1

[a] less than 1%

regions of the world. The largest proportion of RSM to imports is for copper, averaging 4% for the world, and making up over 30% of the former Soviet Union copper imports. Such a large percentage for the former Soviet Union reflects a relatively small (2.5%) import volume compared with total domestic consumption (vs. 7.4% for North America or 24.9% for Europe). The proportions for other metals, however, amount to much less than 1% and, therefore, minimal impacts are expected from RSM supply.

Another measure compares the quantity of projected RSM available annually to the annual volatility of scrap consumption (based on United Nations 1991). Annual scrap consumption data were available only for iron and steel. A simple estimate of volatility was computed as the average absolute value of the year-to-year change in iron and steel scrap consumption over the period. The ratios computed from this quantity are shown in Table 4. This measure indicates that the quantity of iron and steel scrap available to be recycled each year averages a little more than 2% of the year-to-year volatility from 1985 to 1989. Thus, this measure also suggests that the market impact of recycling iron and steel will be minimal.

TABLE 4 Comparison of Projected Average Annual Flows of Radioactive Scrap Iron and Steel Available from Power Plants, with Scrap Iron and Steel Consumption Volatility, 1985-1989

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

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

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

[c] less than 1%

HEALTH RISKS

Both the recycling and the disposal/replacement alternatives for radioactive scrap metal management involve health risks from radiological and chemical exposures of workers and the public and potential industrial and transportation accidents. Of these the greatest risks are associated with accidents.

Radiological health risks

Radiological risks to workers and the public from either the RSM recycling/reuse or disposal and replacement alternatives are very low. Dose estimates are calculated for each of the major population groups and exposure situations that were identified. These include commercial smelter and metal product fabrication and distribution workers, the public exposed to items released for reuse or products made with recycled RSM, the public exposed to smelter emissions, workers and the public exposed during RSM transportation, and the public exposed through RSM disposal in a municipal landfill or smelting residuals disposed in a LLW repository. Estimates of radiological risks associated with 50,000 t of RSM under either alternative are developed.[3]

A tiered -release approach was considered for the recycling alternative because it has the advantage of matching RSM supply with product demand while controlling public health risks and environmental impacts to meet international guidelines. Health risks

[3]The methodology employed has since been embodied in the RESRAD-RECYCLE code under development at Argonne National Laboratory.

are controlled by tailoring release levels to both the radiological characteristics of the scrap and its potential end uses. Four major types of material release are considered: unrestricted reuse of items in their original form, unrestricted recycle of melt-decontaminated metal into new products, prescribed initial use of metal products produced in a controlled environment, and controlled recycling within the nuclear industry.

For illustrative purposes, the release levels for the tiers are derived on the basis of limiting the public individual dose to 10 μSv/yr and collective dose to 1 person-Sv for an annual practice (International Atomic Energy Agency 1988). On this basis, lifetime cancer fatality risks to individual members of the public, including industrial workers, from recycling 50,000 t of RSM would be less than 10^{-6}. Risks to the collective population exposed would be less than 0.1 fatality. For the RSM disposal alternative, radiological risks from exposure of the public as a result of RSM disposal are assumed not to exceed regulatory limits of 10^{-5}. Overall, the level of individual risk to the public is likely to be slightly lower for recycling than for disposal due to the greater stringency of the dose constraints that apply to the processes involved. Individual risks to nuclear workers do not differ between the alternatives because they are subject to a regulatory limit of 10^{-3} for either recycling or disposal. For replacement of disposed RSM, the upper range of risks to metal miners from natural occurring radioactivity, mainly radon (United Nations 1993), is about the same magnitude as the regulatory limits for nuclear workers.

On the basis of the radiological health impact analysis, several conclusions have been reached. Implementation of a tiered-release concept in such standards would provide flexibility in the release of radioactive scrap metals without sacrificing public protection. Different categories of release levels should be established for like groupings of radionuclides. Levels for such a radionuclide group should not be driven by a single nuclide or a few nuclides, such as Co-60 or radon parents. Rather, a separate (and more restricted) release level can be assigned for such cases.[3]

Nonradiological health risks

Both the recycle and the disposal and replacement alternatives involve health risks from worker and public exposures to chemicals that are carcinogenic or toxic, as well as from workplace and transportation accidents. Of these two major types of risks, the fatality risks to the public and workers from accidents are higher and much more immediate than the risks from chemical (or radiation) exposure. Risks are estimated based on 50,000 t of steel.

---

[3] Although the constraining individual doses are generally those for commercial smelter workers, an RSM throughput of 50,000 t results in collective doses for the public that may cause concern (particularly for Co-60) with regard to the criterion of 1 person-Sv for an annual practice. For the unrestricted reuse tier, the activity levels for the nuclide category of radon parents must be quite low to meet the dose constraint of 10 μSv/yr. Determining appropriate release levels is complicated by the fact that radon buildup from decay product ingrowth results in a maximum dose several years following release.

Accidents

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

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

The annual rate of fatalities and major injuries from blast furnace operation (U.S. Department of Labor 1989) is equivalent to 7 fatalities or disabling injuries from pig iron production. The fatality and serious injury rate for iron and steel foundries is also relatively high (U.S. Department of Labor 1989), resulting in an additional risk of 8 fatalities or disabling injuries for production of replacement steel or RSM melting at a commercial smelter. This results in a total risk from steel production processes of about 15 serious injuries or fatalities.

Chemical Exposures

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

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

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

The assumptions used to calculate intake of air emissions from smelting are conservative overestimates for the general population. The calculated inhalation carcinogenic risks associated with the upper estimate of steel production emissions range from 7×10^{-7} for cadmium to 2×10^{-4} for chromium, with a sum risk of 2×10^{-4}.

Although air emissions are the main source of public exposure from smelting, workers may also be exposed to dust in the workplace atmosphere and from slag handling. Smelting residuals could also have impacts on the public, depending on waste disposal practices. The likelihood of adverse impacts to groundwater from these contaminants is low where certain mitigating conditions exist. The likelihood of adverse impacts to surface water from slag is also generally low because of the small fraction of erodible-sized solids (≤0.1 mm), and the likelihood can be further reduced by runon/runoff controls.

Relative magnitude of health risks

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

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

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

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

ENVIRONMENTAL IMPACTS

Impacts to air, land, water, and energy resources from RSM recycle or disposal and replacement are difficult to quantify; a qualitative discussion is presented below.

Impacts on land resources

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

Impacts on water quality

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

Impacts on air quality

Recycling of RSM involves three major types of activities that could generate emissions that would degrade air quality: decontamination, melting in a controlled smelter, and remelting at a commercial mill. The presence of radioactivity and hazardous chemicals requires efficient emission-control technology for exhaust air in decontamination and melting activities, so emissions from these activities are likely to be negligible. Controls would likely be less stringent on emissions from commercial steel mills where the RSM would be remelted and some air quality impacts could occur.

However, emissions from recycling are less than those from primary metal smelting because many impurities have previously been removed and less energy is generally required for recycling. For the disposal and replacement option, substantial impacts to air quality would result from metal replacement activities. Most air emissions generated in metal production come from the ore enrichment and refining processes, and, in the case of steel, from coke production.

Impacts on energy resources

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

Relative magnitude of environmental impacts

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

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

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

CONCLUSIONS

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

The health and environmental impacts associated with the two RSM management alternatives are compared in Table 5. Overall, recycling of RSM is likely to result in fewer impacts than disposing of and replacing it. The health and environmental impacts of recycling are clearly lower, in that health risks of recycling are almost half those for disposal/replacement and environmental impacts are orders of magnitude lower. The comparison of socioeconomic impacts is less clear. RSM disposal will be very costly and will adversely impact availability of low-level waste disposal capacity for materials that are impractical or infeasible to recycle. On the other hand, some public opposition to RSM recycling is likely, regardless of how low the risks may be. The extent of public acceptance of recycling is likely to be affected by the quality of the regulatory process and the provision of information regarding comparative risks of the RSM management alternatives.

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

TABLE 5 Comparison of Impacts from the Radioactive Scrap Metal Management Alternatives

Impact Categories	Impacts from RSM (Steel) Management Alternatives: Recycle/Reuse	Dispose and Replace
Human Health Effect Risk[a]		
Radiological risk	10^{-7} to 10^{-6} fatal cancer risk to metal workers and public; 10^{-2} to 10^{-1} population risk per year of practice	Potential elevated cancer risk to miners
Nonradiological risks		
Accidents (work place)	About 7 fatalities or serious injuries to workers	About 15 fatalities or serious injuries to workers
Accidents (transportation)	10^{-2} collective fatality risk to workers and public	10^{-2} collective fatality risk to workers and public
Chemical exposure from smelting	10^{-3} fatal cancer risk to workers; 10^{-4} to public	10^{-3} fatal cancer risk to workers; 10^{-4} to public
Chemical exposure from coke production	None	1 fatal cancer risk to workers; 10^{-2} to public
Environmental Quality and Resource Use		
Land disturbance	Minimal	Substantial
Water quality degradation	Minimal	Substantial
Air quality degradation	Moderate	Moderate
Mineral resource requirement	Minimal	Substantial
Energy requirement	Moderate	Substantial

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

REFERENCES

American Nuclear Society. World List of Nuclear Power Plants. Nuclear News. 35(10); 1992.

British Geological Survey. World mineral statistics 1985-1989. Keyworth, Nottingham, UK: 1991.

Commission of the european Communities. Recommended radioljogical protection criteria for the recycling of metals from the dismantling of nuclear installations. EURO295 (ED/BS) draft. Luxembourg: 1995.

Dong, M.H., et al. Am. J. Epidemiol. 128:860-873; 1988. [As cited in British

Carbonisation Res. Assoc. Qtrly 39:31-65].

Hertzler, T., et al. Recycle of DOE radiologically contaminated metal — a scoping study. Draft. Idaho Falls, ID: Science Application International Corp.; 1993.

Institute of Scrap Iron and Steel Inc. Metallic scrap: the manufactured resource. Washington, DC: 1984.

International Atomic Energy Agency. Clearance levels for radionuclides in solid materials: application of exemption principles. IAEA-TECDOC-855. Vienna, Austria: 1996.

International Atomic Energy Agency. Principles for the exemption of radiation sources and practices from regulatory control. IAEA Safety Series No. 89. Vienna, Austria: 1988.

International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Oxford, UK: Pergamon Press; 1991.

Johnson, W., and J. Paone. Land utilization and reclamation in the mining industry, 1930-80. Information Circular 8862. Washington, DC: U.S. Department of the Interior, Bureau of Mines; 1982.

Menon, S., and L. Teunckens. Application of exemption concepts: overview of practices in some countries. presented at Waste Management '94. Tucson, AZ: February 27 - March 3, 1994.

Nieves, L.A. and R.W. Tilbrook. Potential radioactive scrap metal quantities from nuclear power plants worldwide. Radwaste. 3(1): 45-53; 1996.

Nieves, L.A., S.Y. Chen, E.J. Kohout, B. Nabelssi, R.W. Tilbrook, and S.E. Wilson, Evaluation of radioactive scrap metal recycling. ANL/TM-50. Argonne, IL: Argonne National Laboratory; 1995.

Nuclear Energy Agency, Organization for Economic Co-operation and Development. Report of the task group on recycling, reuse and release of materials from nuclear facilities. Draft. Paris, France: 1995.

Nuclear Engineering International. World nuclear industry handbook 1991. Surrey, UK: 1991.

Nuclear Engineering International. World nuclear industry handbook 1992. Surrey, UK: 1992.

Nuclear Engineering International. World nuclear industry handbook 1993. Surrey, UK: 1993.

Saricks, C., and T. Kvitek. Trends in state-level freight accident rates: an extension of risk factor development for RADTRAN. presented at 71st Annual Transportation Research Board Meeting. Washington, DC: 1991.

U.S. Department of Labor. Occupational injuries and illnesses in the united states by industry, 1987. Bureau of Labor Statistics Bulletin 2328. Washington, D.C.: 1989.

U.S. Department of Energy. Energy technologies and the environment: environmental information handbook. DOE/EH-0077. Washington, DC: 1988.

U.S. Department of Labor. Injury Experience in Metallic Mineral Mining, 1990. Information Report 1201. Denver, CO: Mine Safety and Health Administration; 1991.

United Nations. Iron and steel scrap: its significance and influence on further developments in the iron and steel industries. New York, NY: Economic Commission for Europe; 1991.

United Nations. Sources, effects, and risks of ionizing radiation. New York, NY: United Nations Scientific Committee on the Effects of Atomic Radiation; 1993.