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Risk and impact tradeoffs in radioactive scrap metal management☆

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Abstract

Two management alternatives for radioactive scrap metal were evaluated: (1) recycling and reuse, and (2) disposal and replacement. The human health risks, environmental impacts, and sociopolitical issues potentially associated with these alternatives were assessed in an international context. For each alternative, the health risks from workplace and transportation accidents are greater in magnitude than the risks from potential exposure to radioactive materials or chemicals. The nonradiological risks are at least twice as high for disposal and replacement as they are for recycling, with the result that recycling has lower health risks overall. Environmental impacts from disposal and replacement of scrap metals are likely to be orders of magnitude higher than those for recycling. This is true of effects on land, water, and air quality, as well as for mineral and energy resources. In addition to risks and costs, issues affecting the choice between radioactive scrap metal management alternatives include low-level waste disposal site availability, public acceptability of recycling, potential impacts on metal markets, impacts of radioactivity on sensitive industrial uses of metal, and international equity issues.

Keywords: Environmental impacts; Health risks; Radioactivity; Recycling; Scrap metal

1. Introduction

This study evaluates the health risks, environmental impacts, and socioeconomic issues associated with alternatives for management of radioactive scrap metal (RSM). Illustrative examples are presented for iron and steel scrap because it comprises a major portion of the potential scrap volume. Both radiological and nonradiological

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risks to human health are assessed, but the treatment of radiological risks is more detailed because of the need to explore issues related to potential development of international standards for recycling. Environmental impacts are discussed in terms of the nature and relative magnitude of effects on environmental quality and resources. Socioeconomic impacts are treated in terms of the major social and political issues associated with implementing the alternatives. Finally, the overall impacts of RSM management alternatives are compared.

2. Alternatives for radioactive scrap metal management

Current and potential sources of RSM include nuclear power plants, nuclear fuel cycle facilities, weapons production facilities, research and development reactors, high-energy accelerators, industrial sterilizer plants, industrial radiography equipment, medical facilities and equipment, and petroleum and phosphate rock extraction equipment. An estimated 3×10^7 metric tons (t) primarily of scrap iron and steel, stainless steel, and copper – with lesser portions of aluminum, nickel, lead, and zirconium – are likely to become available in the future as these facilities are withdrawn from service [1]. 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.

2.1. Recycling

To date, relatively small quantities of RSM from various facilities have been recycled for public use, whereas thousands of tons have been recycled within the nuclear industry [2]. The magnitude of the potentially available supply and the very low level of radioactivity in a major portion of it warrant consideration of a broad range of end uses for this material. A tiered system of release criteria for a wide range of end uses has been 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.

Fig. 1 provides an overview of the RSM recycling process that is evaluated. Tiers A and B pertain to unrestricted release, whereas Tier C pertains to prescribed initial use in the public domain and Tier D involves recycling within the nuclear industry. RSM from the source facility could be released for unrestricted *reuse* if it met, or could be decontaminated to meet, the Tier A-1 surface and A-2 volumetric activity limits. Tier A-1 applies to objects with removable surface contamination that are released in their original form (e.g., office furniture, tools, or structural steel). In contrast, Tiers A-2, B, and C pertain to scrap with fixed-surface or volumetric activity that would be decontaminated (Tier A-2) and melted (Tier B) in a controlled (licensed) facility before being released for unrestricted *recycling*. Melting would serve as a decontamination measure for some radionuclides and also would facilitate measurement and certification of the activity in the metal. Tiers A-2, B, and C include a wide range of metal

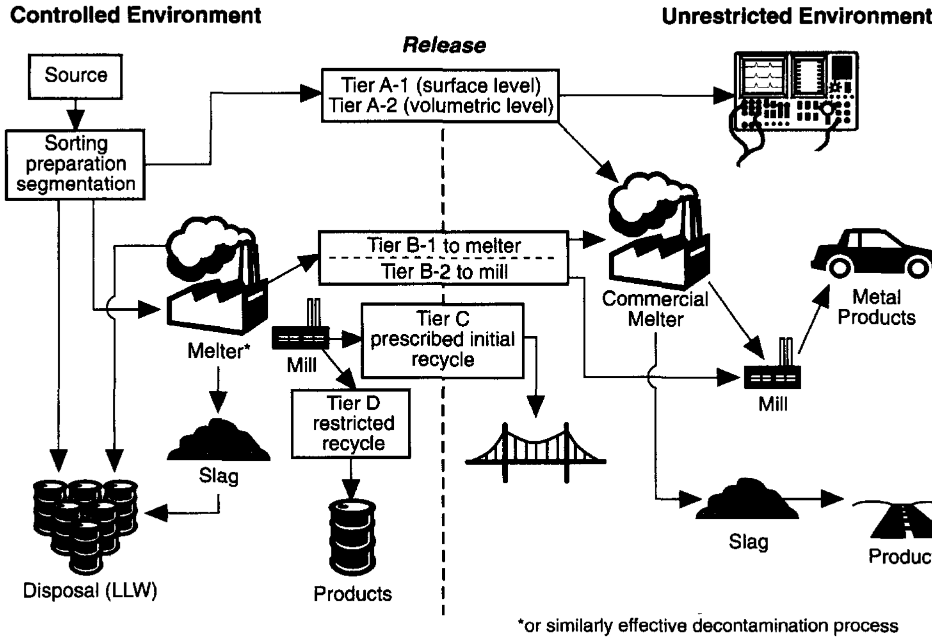

Fig. 1. Process for assessment and release of radioactive scrap metal.

product end uses. These products would be made from ingots that are remelted at a commercial melter (Tiers A-2 and B-1) and/or fabricated into products at commercial mills (Tiers A-2, B-1, and B-2). Slag from the commercial melting is assumed to be used in paving highways or parking lots. Tier C release requires distribution of finished metal from the controlled facility only to a limited set of specified initial uses that involve minimal public exposure. When the metal is again recycled (30 years assumed), it would be treated as common scrap. The main advantage of Tier C end uses is the ability to control health risks from recycling metals that are contaminated with relatively short-lived radionuclides. Metal with activity exceeding Tier C limits would be recycled for use in environments with radiation controls (Tier D), e.g. as containers for waste disposal. If recycling were judged technically or economically infeasible, scrap would be disposed of as low-level waste (LLW).

2.2. Disposal and replacement processes

The alternative to recycling RSM is to dispose of it in an unrestricted landfill or a LLW disposal facility. This requires cutting and packaging RSM for transportation and disposal and may 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. The discarded metal would be replaced by metal newly produced from ore, which involves mining of ore, ore enrichment or refining, metal smelting, casting, and fabrication, as well as production of the energy required for these activities.

3. Radiological health risks

For the RSM recycle alternative, radiological health risks were estimated for Tier A, B, and C end-use scenarios, as well as for emissions from commercial smelting and for unrestricted landfill disposal. Potential health risks were assessed for commercial metal workers and the general public. Health risks from activities of radiation workers prior to RSM release – such as metal sorting, decontamination, and packaging – were not evaluated because these activities would take place in an environment where exposures are controlled below regulatory limits and they might be required for either recycling or disposal of RSM. Disposal of RSM at a LLW site would also be carried out by radiation workers and exposures would be controlled. Therefore, the associated risk estimates are based on regulatory limits and previous studies [3, 4].

Potential radiological impacts from the RSM alternatives were assessed in terms of the total effective dose equivalent (10 CFR 20) [3], which is the sum of the effective dose equivalent from external exposures and the committed effective dose equivalent from internal exposures. Health impacts, expressed in terms of cancer fatalities, were obtained by multiplying the total effective dose equivalent by the health effects conversion factor of 5×10^{-2} fatal cancers per Sievert (Sv) [5].

Radiological risks from both RSM management alternatives (based on 50 000 t of RSM) are low. Radioactivity levels for the unrestricted release tiers are derived to limit dose to any member of the public to 10 μSv/yr [6], so cancer fatality risks to individual members of the public, including industrial workers, from a year of unrestricted recycling activity would be less than 10^{-6}. Based on IAEA Safety Series 89 [6], collective dose has been specified to be less than 1 person-Sv per year per recycle practice. This corresponds to an annual cancer fatality risk of 5×10^{-2}. Radiological risks from public exposure as a result of RSM transportation and disposal, are assumed not to exceed regulatory limits of 1 mSv/yr (100 mrem/yr) [3]. Metal replacement activities may also result in public doses from emissions to air and water. The upper range of individual risks to metal miners (involved in replacement activities) from natural occurring radioactivity, mainly in the form of radon [7], is about the same magnitude (10^{-3}) as the US regulatory limits for radiation workers [3].

4. 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 and 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. In addition, steel replacement involves accident risks in both iron and coal mining, in coking coal production, and in pig iron production. Chemical exposures for workers and the public from smelting operations are likely to be similar for RSM recycling and replacement. In addition, replacement would result in worker and public exposure to chemicals from iron and coal mining, coking coal production, and pig iron production.

4.1. Accidents

Accident risks from transportation and smelting operations apply to both RSM recycling and replacement alternatives. Based on US interstate highway accident fatality rates [8], about 7×10^{-3} to 1.3×10^{-2} fatalities would be expected from recycling 50 000 t (assuming two 100 km transport segments). Shipment of the same quantity one way for disposal would have a risk of $3.5–6.5 \times 10^{-3}$ fatalities. In addition, both iron ore and coking coal for replacement steel would require transportation to the steel foundry, resulting in an additional risk of 2.6×10^{-3} to 8.6×10^{-2} fatalities (based on bulk transport) [9].

Replacement of RSM would involve accident risks for workers involved in metal and coal mining activities. For 50 000 t, the US fatality rates would result in a risk of 10^{-2} fatalities for metal miners [10] and 1.6×10^{-3} to 3×10^{-2} for coal miners [11]. In addition, steel replacement involves accident risks in coking coal production which were not quantified. An additional 7 fatalities or disabling injuries would be expected from blast furnace operations required to produce pig iron from the ore. For both recycling and replacement, about 7.5 fatalities or disabling injuries are likely in the iron and steel foundry processes to finish the steel [11].

4.2. Chemical exposures

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

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 [12] is 1.1×10^{-2} to 6×10^{0} for workers, depending on emission controls, and 1.1×10^{-3} to 7×10^{-2} for the public.

5. Environmental impacts

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

Table 1
Environmental impacts associated with radioactive scrap metal (steel) management alternatives

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

types of environmental effects likely to be associated with each alternative are summarized in Table 1.

5.1. Land use/disturbance

Impacts to land use from recycling RSM would be relatively minor. The main requirements are the development of facilities for decontamination and melting of RSM. About 10% of the inputs to controlled smelting would require disposal as LLW in the form of slag.

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 [13]. In addition, huge piles of mining wastes and ore tailings may be left exposed, from which toxic chemicals would continue to be leached. The waste quantities are commonly one-hundred times the quantity of ore extracted, or more.

5.2. *Water quality/resources*

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.

Disposal is also unlikely to adversely impact water supplies. 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.

5.3. *Air quality*

Recycling RSM involves three major activities that could generate emissions that would degrade air quality: decontamination, melting in a controlled melter, and scrap remelting at a commercial mill. The presence of radioactivity and hazardous chemicals is likely to require efficient emission-control technology for exhaust air in decontamination and melting activities, so emissions from these activities are likely to be negligible. Regulatory controls would likely be less stringent on emissions from commercial steel mills where the scrap would be remelted, and some air quality impacts are likely. However, 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 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 smelting processes, and, in the case of steel, from coke production as well. Steel mills typically release relatively large quantities of gases that contribute to urban smog and acid precipitation, as well as a variety of toxic or carcinogenic gases and particulates. Coke oven emissions, generated when coal is converted to coke for use in producing pig iron, are even more detrimental. In the more industrialized countries, recent emphasis on environmental protection has led to controlling a portion of the emissions from both smelters and coke ovens.

5.4. *Mineral and energy resources*

Production of 1 t of steel entirely from scrap metal requires approximately 10.5 GJ of energy [14]. Starting from raw materials, the energy requirement ranged from 21 to 35 GJ/t and averaged 28.7 GJ/t for the USA in 1991. Thus, the energy requirement for metal 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 for recycling RSM is still likely to be less than for replacement.

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 for the coke results in numerous tons of wastes. Substantial land areas are disturbed or contaminated by toxic metals in this process and are generally not reclaimed. Both toxic and radioactive elements would be released to surface waters, and rivers would 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.

6. Socioeconomic issues and impacts

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

6.1. LLW disposal site availability

Disposal of the potential international RSM inventory as LLW would require a disposal site capacity of approximately 5×10^6 m^3 (assuming uncompacted metal with 30% void space). Although new LLW disposal facilities are anticipated to become available, disposal costs in the USA 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 [15]. Because siting and operation of LLW disposal facilities is a significant issue in a number of countries, there are major political constraints on capacity availability.

Disposal of the entire RSM inventory would result in about $9 billion in disposal costs alone at current US rates for surface disposal. However, more than half of the power plant metal masses are either essentially nonradioactive or could be easily decontaminated. Thus, if a major portion of the scrap metal from power plants can be reused or recycled, disposal cost savings and reductions in disposal capacity requirements could be substantial. However, the option of RSM recycling does not entirely eliminate the need for LLW disposal. Residues from chemical, mechanical, or melting decontamination processes would still require LLW disposal, but quantities would be much smaller than for the disposal and replacement alternative.

6.2. Public acceptability

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

With regard to public acceptance, RSM recycling is at a disadvantage (compared with many other activities with equally low probability of adverse effects) because of the stigma currently associated with the nuclear industry in most industrialized countries. This stigma has largely been avoided by the metals, petroleum, phosphate, and coal production industries, in spite of releasing substantial quantities of naturally occurring radionuclides to the environment. As a result, a RSM recycling process that serves a broad range of industries may be more acceptable to the public than one that solely or primarily serves the nuclear industry.

RSM disposal and replacement activities may also encounter problems with public acceptance. Metal mining involves some worker and public exposure to elevated background radiation (especially in copper mining), but public awareness of the risks is minimal. Nonradiological environmental and health impacts of metal mining and smelting, although relatively large, are generally familiar and acceptable to the public. In contrast, public perception of LLW disposal risks generally has the same heightened sensitivity that is associated with nuclear industry activities. As a result, the option of RSM disposal and replacement is also unlikely to be readily acceptable to the public. Siting and licensing of both high- and low-level waste facilities have encountered intense opposition in a number of countries. In this situation, information on the relative risks of the RSM management alternatives may play a major role in public perception and decision making.

6.3. Impacts of recycling or replacement on metal markets

Estimation of the potential quantities of RSM worldwide is hindered both by a lack of published data and by the uncertainty associated with weapons facilities. It is likely that three categories of facilities – nuclear power, fuel cycle, and weapons production – are the largest potential sources of contaminated scrap metal, although the quantity of naturally contaminated petroleum extraction equipment and piping may also be substantial [16]. The total worldwide inventory of potential steel scrap from these sources would be about 2.5×10^7 t.

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

6.4. Issue of impact shifting

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

The major potential for impact shifting arises in the case of RSM disposal and replacement. Much of the world's ore production and refining occurs in less developed countries and in countries that do not have strong systems for environmental and health protection. The distribution of raw material production among countries and the substantial health and environmental impacts of metal production create the potential for significant impacts in less developed countries if the option of RSM disposal and replacement is implemented.

6.5. Impacts on industrial applications

The choice between recycling or disposing of RSM may be seen as an issue of having a metal supply that is clean versus having one that is radioactive, although the issue is not actually that clear-cut. Iron and steel, for instance, generally contain small amounts of naturally occurring radioactive materials that originate with the ore deposits or with the coal used in coke production. Measured background activities of uranium and thorium in steel are of the order of 10^{-5} to 10^{-4} Bq/g [17]. One of the issues that has been raised in considering recycling of RSM is the possibility of deleterious effects on scientific and technical equipment from low levels of radioactivity in metals. Large-scale integrated circuits, high-sensitivity photographic films, and low-background radiation counters have been identified as particularly sensitive to such effects [18]. Because of the adverse impacts on these technologies, even from existing background radiation levels, practices have been adopted to minimize such effects. For instance, steel made from low-activity raw materials is commonly used as shielding material for whole-body counters. The need to minimize effects of residual radioactivity on some technologies is not new, and use of RSM in sensitive applications can be avoided.

6.6. Regulation for protection of human health

Recycling RSM is currently impeded by the lack of an internationally accepted standard for unrestricted release of this material. Some European countries have developed release standards, but contaminated metals are generally evaluated and released on a project-specific basis. The USA currently has a (nonrisk-based) surface contamination standard for material release, Regulatory Guide 1.86 [19], but none for volumetric activity. Development of worldwide metal recycling will require further effort to determine appropriate activity limits to ensure protection of public health under possible conditions of exposure. Because the international trade in scrap metals and metal products is so extensive, an international standard is needed, rather than individual national standards.

7. Summary and comparison of impacts from recycling and disposal/replacement

The health and environmental impacts and socioeconomic issues associated with the two RSM management alternatives are compared in Table 2. An overview of the major findings is presented below.

7.1. Relative magnitude of health risks

Potential health risks to workers and the general public are associated with both the RSM recycle/reuse and the disposal and replacement management alternatives. 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 limits would constrain radiation exposure of workers and the general public to very low levels under either alternative. Unrestricted recycling of RSM that meets radioactivity limits for Tiers A, B, and C would result in an individual lifetime cancer fatality risk level for the general public of 10^{-7} to 10^{-6} from annual exposure (based on [5]). Risks to commercial metal workers would be of a similar magnitude and could be reduced further by employing protective measures. The total population 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 are more likely for nonferrous metals than for iron mining.

Table 2
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 (workplace)	About 7 fatalities or serious injuries to workers	About 14 fatalities or serious injuries to workers
Accidents (transportation)	10^{-2} fatality risk to workers and public	10^{-2} fatality risk to workers and public
Chemical exposure from smelting	10^{-3} fatal cancer risk to workers; 10^{-4} to public	10^{-3} fatal cancer risk to workers; 10^{-4} to public
Chemical exposure from coke production	None	1 fatal cancer risk to workers; 10^{-2} to public
Environmental quality and resource use		
Land disturbance	Minimal	Substantial
Water quality degradation	Minimal	Substantial
Air quality degradation	Moderate	Moderate
Mineral resource requirement	Minimal	Substantial
Energy requirement	Moderate	Substantial
Socioeconomic issues		
LLW site capacity	Minimal	Substantial
Public acceptability	Varies among countries	Generally accepted except for local concerns
Metal market impacts	Minimal	Minimal
Risk distribution	Risk largely borne in country generating RSM	Risk largely shifted to less developed countries
Industrial applications	Minimal	Minimal

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

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

7.2. *Relative magnitude of environmental impacts*

The environmental impacts associated with the recycling and disposal alternatives for RSM are quite different. 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 ore refining processes, and energy requirements would be much greater than is the case for recycling scrap metal.

For steel, the environmental impacts are substantially larger for replacement than for recycling in virtually all categories. Estimates of the benefits from using scrap instead of ore to produce steel indicate reductions of 90% in raw material consumption (mainly coal), 86% in air emissions, 40% in water consumption, 76% in water pollution, and 97% in mining wastes [20]. Only in the air emissions category do impacts of the recycling process overall 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 RSM are likely to be smaller because many impurities would have previously been removed. In addition, recycling scrap would require two to three times less energy, thus reducing secondary impacts from fuel combustion as well.

7.3. *Relative magnitude of socioeconomic impacts*

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

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

The issue of possible impacts on sensitive technologies from radioactivity in the metal supply has also been found to have minimal impacts. This issue has to be, and has been, dealt with regardless of whether RSM is recycled because many types of finished metal contain low levels of radioactivity.

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

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

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